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SOUTHEAST ASIA
A CLIMATOLOGICAL STUDY

By

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13. Abstract: A climatological study of southeast Asia, a region that comprises Cambodia, Laos, Myanmar, Malaysia, Thailand, and Vietnam. After describing the geography and major meteorological features of the entire region, the study discusses in detail the climatic controls of each of southeast Asia's six "zones of climatic commonality." Each "season" is defined and discussed in considerable detail, to include general weather, clouds, visibility, winds, precipitation, temperature, hazards, and trafficability.

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PREFACE

This study was prepared by the Air Force Combat Climatology Center's Readiness Support Branch (AFCCC/DOJ), in response to a support assistance request (SAR) from the Air Force Global Weather Center (AFGWC), Offutt AFB, Neb.

The project would not have been possible without the ded[illegible]ated support of the many people and agencies listed below. First, thanks to Dr. Carol Weaver for the techn[illegible]sistance and advice in making this document easier to read. We also appreciate the assistance of Mr [illegible] McCollom, Mr. David Pigors, Mr. Charles Travers, Mr. Gary Swanson, Ms. Susan Keller, Ms. Susan [illegible]arbell, Ms. Lisa Mefford, and Ms. Randa Simon of the Air Weather Service Technical Library. Without their help, much of the information in this document, necessarily obtained from multiple sources, would simply not have been made available to us.

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TABLE OF CONTENTS

FIGURES

Chapter 1

INTRODUCTION

Area Of Interest. This study describes the geography, climatology, and meteorology of southeast Asia. Figure 1-1 shows the six "zones of climatic commonality."

Figure 1-1. Southeast Asia and Its Six "Zones of Climatic Commonality."

• ***Northern Myanmar.*** Northern Myanmar (formerly known as Burma) is far enough north to be routinely affected by frontal systems, but its proximity to the Indian Ocean allows it to be strongly influenced by the southwest monsoon, as well. The mean 10-degree (Celsius) annual temperature variation line establishes the zone's southern boundary. This dividing line was chosen because it provides a close approximation of the boundary between zones that have four conventional seasons (north of the line) and those governed by two monsoon seasons (south of the line).

• ***Northern Vietnam.*** Like Northern Myanmar, this zone is routinely affected by frontal systems and has conventional temperate-zone seasons (winter, spring, summer, and fall). Again, the 10-degree (Celsius) annual temperature variation line establishes the zone's western boundary. The 50-mm January precipitation line marks the southern boundary.

• ***West-Facing Coasts.*** This zone includes western Myanmar and the southern portions of Thailand, Cambodia, and Vietnam. The area is extremely wet during the southwest monsoon because of its direct exposure to the Bay of Bengal on the west and the Gulf of Thailand on the east. The northern boundary is the line at which annual temperature variation exceeds 10 degrees Celsius. The eastern boundary is the line inside of which annual rainfall exceeds 1,600 mm.

• ***Central Southeast Asia.*** This zone includes northeastern Myanmar, northern Thailand and Cambodia, and all of Laos. This interior zone, where the relationship between topography and wind direction determines rainfall patterns, is drier than coastal areas. The area is very dry during the northeast monsoon. The northern boundary is where the mean annual temperature variation exceeds 10 degrees Celsius. In some places, Vietnam establishes the eastern boundary; in others, the 50-mm January precipitation line establishes the boundry. The western boundary is the line outside of which the annual rainfall exceeds 1,600 mm. The southern boundary is the shore of the South China Sea.

• ***Central Vietnam.*** This zone is affected by frontal systems as well as by the colder waters off the coast during the northeast monsoon, which is unusually wet here. The northern and southern boundaries are marked by the 50-mm January precipitation lines. The western boundary follows the Laotian border until it intersects the 50-mm January precipitation line.

• ***Malay Peninsula.*** This zone has a truly equatorial climate. Wet the year-round, its diurnal temperature variation exceeds its annual temperature variation. Its northern border is marked by the 50-mm January precipitation line.

Study Content. Chapter 2 provides a general discussion of the major meteorological features that affect southeast Asia. These features include semipermanent climatic controls, synoptic disturbances, and mesoscale and local features. The individual treatments of each zone in subsequent chapters do not repeat descriptions of these phenomena; instead, they discuss specific effects of these features unique to that zone. Therefore, meteorologists using this study should read and consider the general discussion in Chapter 2 before trying to understand or apply the individual climatic zone discussions in Chapters 3 through 8. This is particularly important because the study was designed with two purposes in mind, a master reference for southeast Asia, and a modular reference for each individual zone.

Chapters 3 through 8 amplify the general discussions in Chapter 2 by describing the geography, climate, and meteorology of the six "zones of climatic commonality," which are shown in Figure 1-1. These chapters provide detailed discussions of these six zones, each known to feature reasonably homogeneous climatology and meteorology. In mountainous areas, however, weather and climate are not necessarily internally homogeneous. Weather in one mountainous area can be distinctly different from an area immediately adjacent.

In each zone, geography is discussed (including topography, rivers and drainage systems, lakes and water bodies, and vegetation). Next, major climatic controls, and if appropriate, special climatic features are described. Weather for each season is then discussed and organized in the following categories:

- General Weather
- Sky Cover
- Visibility
- Winds
- Temperature
- Precipitation
- Other Hazards

All the zones except Northern Myanmar and Northern Vietnam have wet and dry (or warm and cool) seasons instead of standard temperate-zone seasons (winter, spring, summer, and fall). The transitions between seasons are, in some cases, too short to warrant separate discussions. The length of each season varies from zone to zone.

Conventions. The spellings of place names and geographical features are those used by the National Imagery and Mapping Agency (NIMA). Distances and elevations below 10 kilometers are given in meters and in kilometers (km) above that level. Cloud and ceiling heights are in feet. When the term "ceiling" is used, it means 5/8 cloud coverage or greater *at any level* unless specified otherwise. Temperatures are in degrees Celsius (°C). Wind speeds are in knots. Precipitation amounts are in millimeters (mm). Most synoptic charts are labeled in Universal Coordinated Time (UTC or Z). When synoptic charts are not provided, only local time (L) is used. Unless otherwise stated, cloud bases are above ground level; tops are above mean sea level. Since cloud bases are generalized over large areas, readers must consider terrain in discussions of cloud bases in and around mountains.

In figures showing mean monthly rain, snow, and thunderstorm days, "rain days" include those on which WMO present weather codes 21, 23-26, 50-69, 80-84, 91, 92, 94-97, or 99 are reported. "Snow days" include days on which present weather codes 22, 23, 70-75, 77, or 85-88 are reported. "Thunderstorm days" are those on which codes 17 or 91-99 are reported. Codes 40-49 indicate a "fog day."

Data Sources. Most of the information used in preparing this study came from two sources, both within AFCCC. Studies, books, atlases, etc. were supplied by the Air Weather Service Technical Library (AWSTL). Climatological data came direct from the Air Weather Service Climatic Database through OL-A, AFCCC—the branch of AFCCC responsible for maintaining and managing this database.

Related References. This study, while very comprehensive, is certainly not the only source of climatological information for the military meteorologist concerned with southeast Asia. Staff weather officers and forecasters are urged to contact the AWSTL for more data.

Chapter 2

MAJOR METEOROLOGICAL FEATURES OF SOUTHEAST ASIA

Sea-Surface Conditions. Ocean currents play an important role in determining the region's climate. The major currents affecting southeast Asia are shown in Figure 2-1 and described below. The strength and position of most of these currents fluctuate during the year, with only the South Equatorial and Kuroshio currents present year-round.

The northeastward-flowing, warm Kuroshio Current is the primary current of the western Pacific Ocean. It is the second strongest ocean current in the world, after the Atlantic's Gulf Stream. Although the Kuroshio Current is always present, its strength and direction vary considerably from year to year.

The Indian Ocean's South Equatorial Current is strongest in August when it forms a large clockwise eddy with the Southwest Monsoon Current. Upwelling caused by the South Equatorial Current brings cooler water to the northwestern Australian coast from April to September.

The Southwest Monsoon Current, present from June through October, is strongest close to Sumatra. By December, it is replaced by the North Equatorial Current.

The North Equatorial Current is strongest in January and February, when a large clockwise eddy forms in the Bay of Bengal. To the south, a weak eddy flow separates it from the Equatorial Countercurrent.

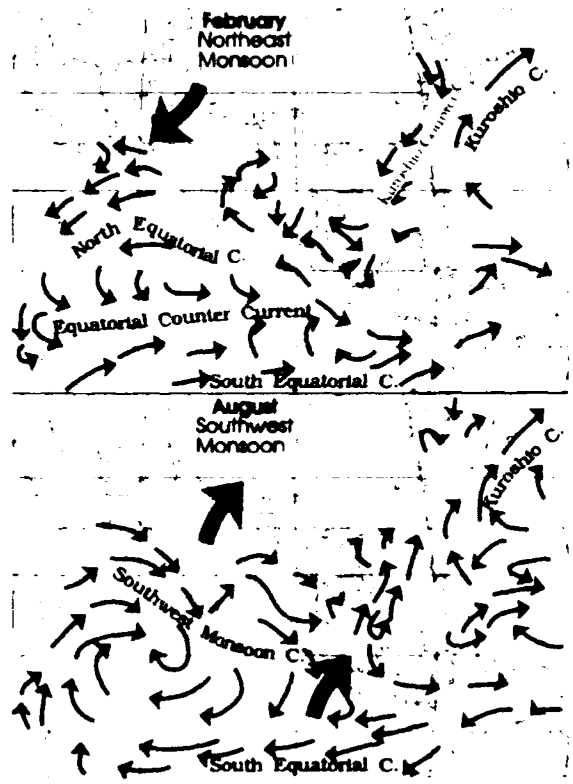


Figure 2-1. Ocean Currents during February and August (Wells, 1986). Large arrows indicate prevailing wind direction.

The eastward-flowing Equatorial Countercurrent is active between December and April. Its southern boundary is ill-defined as it merges into the South Equatorial Current, but its northern boundary is sharp.

The Kuroshio Countercurrent flows southward along the east Asian coast during the northeast monsoon, drawing cold water into the South China Sea. This causes strong sea-surface temperature gradients along the Vietnamese coast in January and April (see Figure 2-2).

Figure 2-2 shows mean sea-surface temperatures (SSTs) around southeast Asia. Warm waters *destabilize* the atmosphere, which leads to the development of cumuliform clouds. Cold waters *stabilize* the atmosphere, which generally favors stratiform clouds. SSTs are above 25°C throughout the year except in the Gulf of Tonkin, where the Kuroshio Countercurrent brings cold water from the north, and in the northern Bay of Bengal, where several large rivers feed colder water into the bay. The mean position of frontal zones off Vietnam's coast is closely related to the strong temperature gradient there.

Seasonal variations in sea-surface temperatures are small, though temperatures are generally highest in April (except in the northeast). Temperatures can vary significantly from year to year, especially in the deep tropical oceans. Variations in sea-surface temperature are linked to jet stream development and maintenance, and they may trigger typhoon formation.

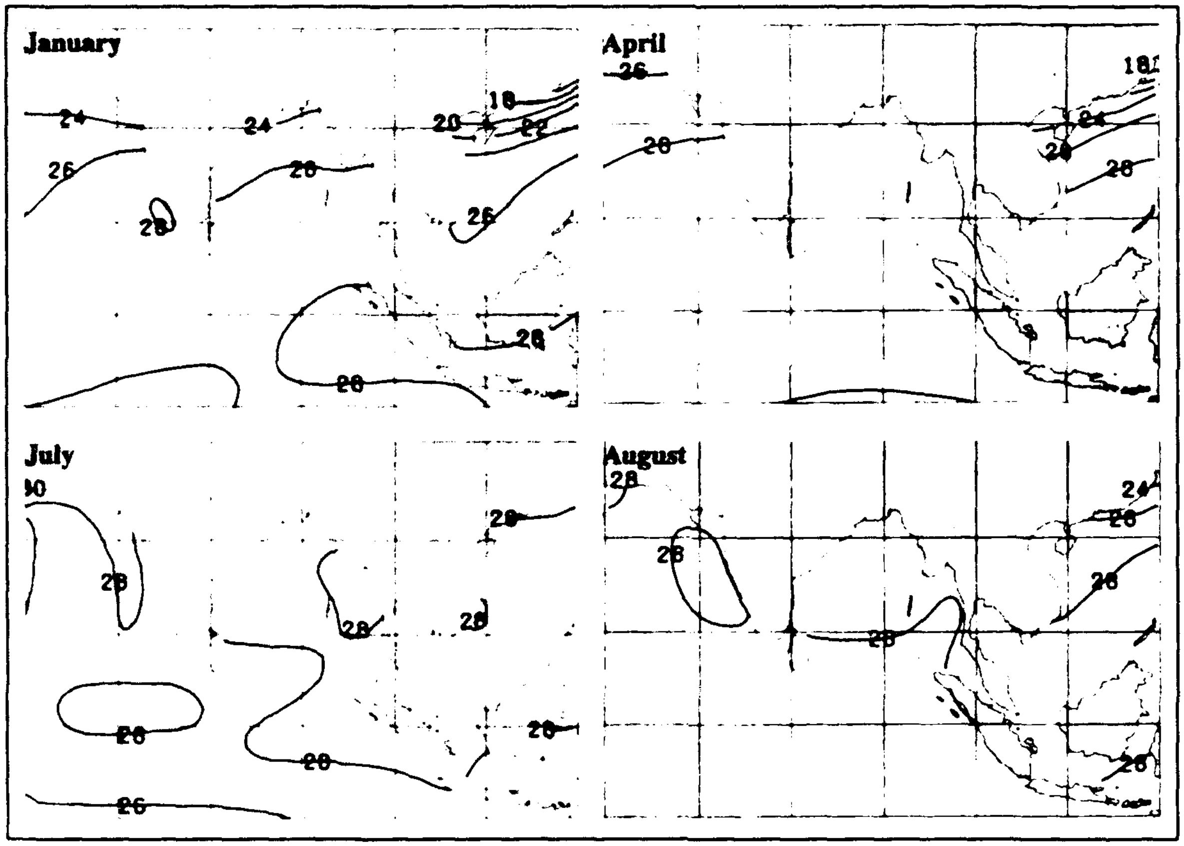


Figure 2-2. Mean Sea-Surface Temperatures (SST) for January, April, July and August. Sea-surface temperatures remain above 25°C except in areas influenced by river mouths and the Kuroshio Countercurrent.

Maritime Pressure Features. These features include the North Pacific high, the South Pacific high, the South Indian Ocean high, and the El Niño cycle.

North Pacific High. This subtropical high, centered off the North American coast, is farthest north and west in July (Figure 2-3). It forms a ridge that extends westward into Asia around 35° N in July and 25° N in January. Its position is linked to the movement of the Near Equatorial Tradewind Convergence (NETWC) (discussed later under "Monsoon Climate") and to oscillations in convective activity in the southwestern Pacific. On its southern side, it causes the North Pacific trade winds that dominate the northeast monsoon between surges of air from the Asiatic high.

During the southwest monsoon, if the North Pacific high lies farther west than normal, a "monsoon break" occurs. During these breaks, the diurnal rainfall pattern shifts from the normal early-morning rains to isolated afternoon and evening showers.

Between September and November, this high retreats very slowly southward over the warm South China Sea and western Pacific. This allows tropical disturbances, such as typhoons, to continue well into winter.

During the northeast monsoon, the North Pacific high over the western Pacific oscillates between a shallow and a deep flow pattern. Each lasts about 10 days, causing fluctuations in the northeast monsoon. This is part of a phenomenon known as the Low Frequency Oscillation. With a shallow high, no 200-mb ridge is evident; strong upper-level westerlies prevail to south of the equator. At 700 mb, easterlies predominate south of the high. Easterly waves tend to develop, typhoons rarely occur, and polar troughs are absent. With a deep high, there is a strong ridge at 200 mb. At 700 mb, equatorial westerlies dominate south of 10° N. Typhoons develop between the northeast trade winds and the westerlies.

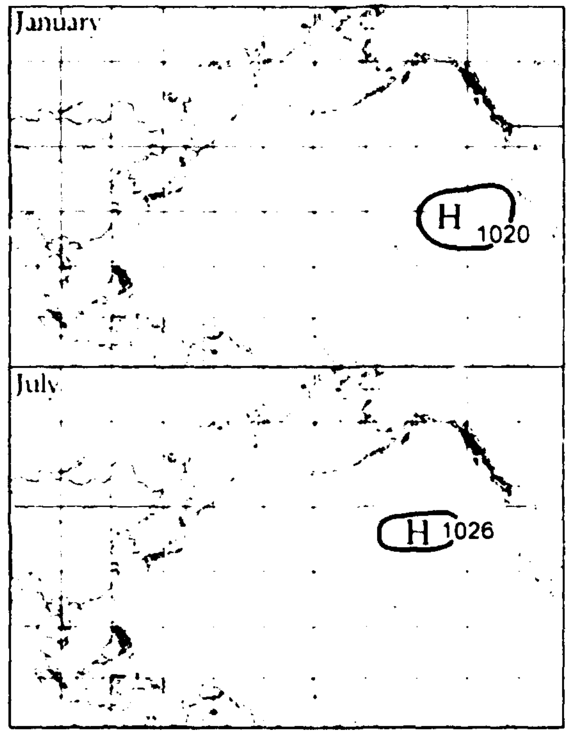


Figure 2-3. January and July Mean Positions of the North Pacific High. The high migrates north and west during the Northern Hemisphere summer.

South Pacific High. This is the Southern Hemisphere's counterpart to the North Pacific high. Mean central pressure ranges from 1,018 mb in March to 1,025 mb in September. The cell migrates from 32° S, 102° W in January to 26° S, 98° W in July. From these mean positions it ridges westward into the western Pacific (the ridging is visible in Figure 2-4). The high slopes equatorward with height.

Outflow from the South Pacific high forms the South Pacific trades. These southeasterly trade winds affect the Malay Peninsula during the southwest monsoon, though they are not very strong and extend to only about 2,500 meters.

The strength and position of this high display a periodicity similar to that of the North Pacific high. This affects typhoon formation in the western Pacific, and the position of the NETWC over the Malay Peninsula.

South Indian Ocean (Mascarene) High. The mean central pressure of the Mascarene high ranges from 1,021 mb in April to 1,028 mb in August, though the pressure can exceed 1,040 mb during the Southern Hemisphere winter. The high's annual movement is mainly east-west from 30° S, 87° E in January to 29° S, 65° E in July (see Figure 2-4). The high slopes equatorward and westward with height.

Cross-equatorial flow from this high is one of the primary drivers of the southwest monsoon flow. Its large east-west movement causes seasonal variations in the strength of the equatorial westerlies.

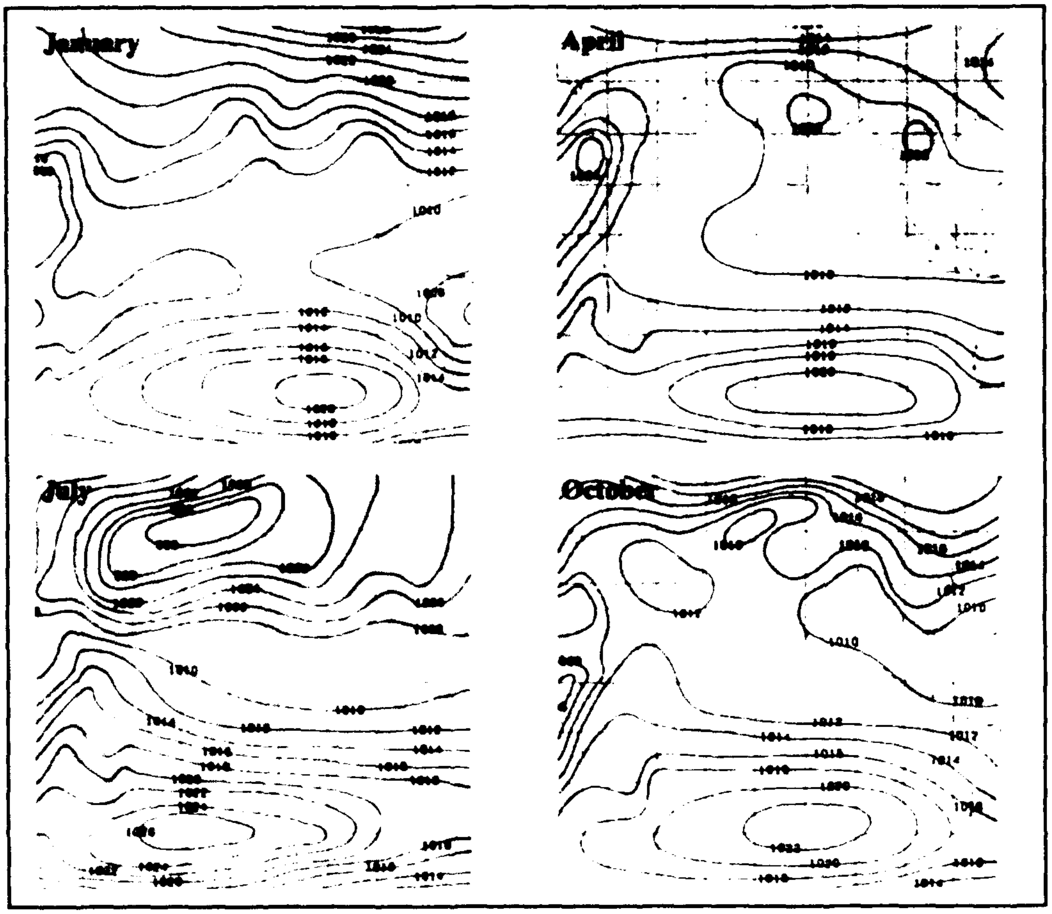


Figure 2-4. Mean Sea-Level Pressure for January, April, July, and October. The figure shows the pressure centers (and how they change during various times of the year) that impact the weather in southeast Asia.

periodic changes in atmospheric pressure, sea-surface temperature, and air temperature. It is characterized by two phases, a warm "El Niño" and a cold "La Niña", with short intervening transitions. The time to complete one cycle varies between 2 and 10 years and averages around 3 years. Atmospheric circulation changes occurring near the equator and in association with these phases are shown in Figure 2-5. Shaded areas in the figure indicate sea-surface temperatures above 27°C.

The El Niño phase lasts an average of 18 months. It begins with elevated sea-surface temperatures in the eastern Pacific, usually in December. These temperature anomalies gradually diminish as they propagate westward, however, and temperatures in the South China Sea and Indian Ocean are 2-3° C

Oscillation are not fully understood, but El Niño also appears to be connected to variations in sea-surface temperatures in the Atlantic Ocean.

El Niño's peak intensity in southeast Asia begins during the southwest monsoon season (June-August) and lasts into the northeast monsoon (September-December). Figure 2-6 shows the areas affected directly or indirectly by the Southern Oscillation. During an El Niño year, June, July, and August are abnormally dry (soutneast Asia's most severe droughts are linked to El Niño). For the next 3 months, the aridity persists in the southeastern portion of the region, and rainfall during the northeast monsoon is as much as 30 percent below average in Malaysia; however, central southeast Asia is unusually wet.

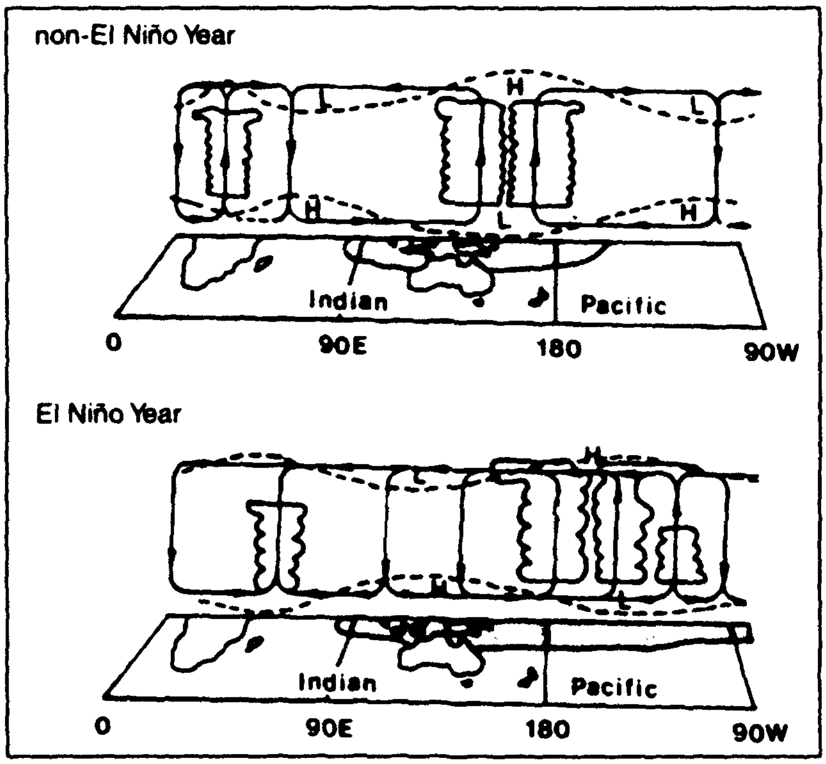


Figure 2-5. Equatorial Circulation Model during non-El Niño Years and El Niño Years. Sea-surface temperatures are above 27°C in shaded areas.

Radical changes to the monsoon system appear to be linked to the El Niño cycle. The North Pacific high strengthens and shifts unusually far south during the southwest monsoon. The high covers a larger area and extends farther westward. Also, the primary convergence zone of the NETWC, which is normally over the Indian Ocean, shifts closer to New Guinea. Both the northern and the southern NETWCs generally disappear during the northeast monsoon and are replaced by easterlies. In the upper troposphere, the subtropical westerlies prevail to the equator. Cold surges occur less frequently, and there are fewer typhoons in El Niño years, particularly between July and November.

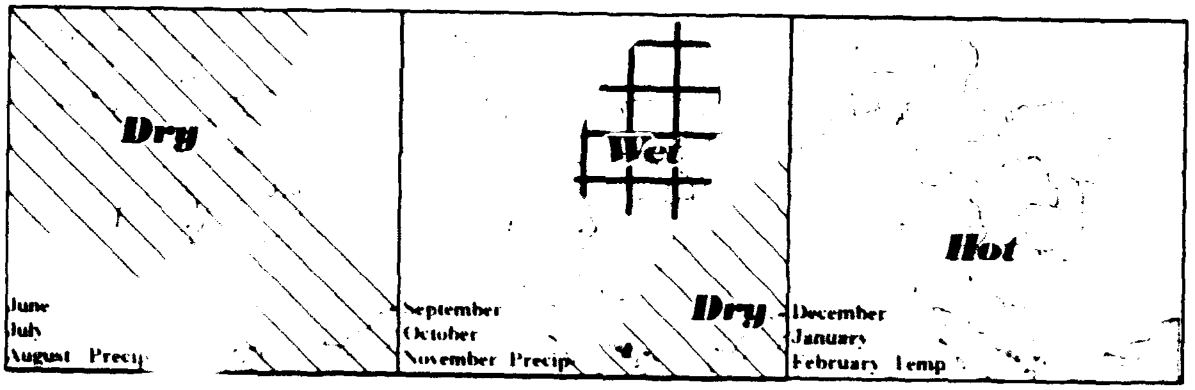


Figure 2-6. Areas **Affected by El Niño.** The figure depicts the hotter, drier climate and shortened typhoon season associated with El Niño.

Continental Pressure Features. These features include the Asiatic high, the Australian high, the Indian high, the West China trough, the India-Myanmar (previously known as the India-Burma) trough, and several heat lows.

Asiatic (or Siberian) High. This is a strong but shallow high-pressure cell that dominates much of the Asian continent from late September to late April. It rarely extends above 850 mb. The mean central pressure is strongest (1,038 mb) in January when the high is centered over western Mongolia (see Figure 2-4). The Asiatic high is created and supported mainly by radiational cooling. Migratory arctic air masses, which produce multiple centers, temporarily reinforce and intensify the high. The central pressure occasionally exceeds 1,050 mb for up to 3 days; the highest recorded pressure is 1,083 mb. Variations in the high result in a 10- to 12-day periodicity in the strength of the northeast monsoon in southeast Asia.

The Tibetan Plateau forms an obstacle that prevents invasions of air from this high into southeast Asia. However, modified air is channelled into the region through the mountains of western Myanmar. Cold air may also be pulled into northern Vietnam by lows that develop in the lee of the mountains. Cold air can penetrate as far south as Singapore, though it is rapidly moderated by the South China Sea.

Australian High. This thermal high is present during the Southern Hemisphere winter. It is strongest in July when it is near 28° S, 128° E with a central pressure of about 1,022 mb (see Figure 2-4). It is neither as strong nor as persistent as the Asiatic high, and it is crossed regularly by disturbances and migratory highs.

Air from the Australian high is warm and dry upon leaving Australia, but the air picks up moisture as it crosses the South China Sea. When the high is unusually strong, it causes subsidence over the Malay Peninsula, which brings dry, calm conditions.

Indian High. This high occasionally develops over India during the winter. Because its intensity and position are highly variable, this high is not evident in the mean charts shown in Figure 2-4. When this high is unusually strong, it produces a north-northwesterly flow over the northern Malay Peninsula. This flow begins as a warm, dry current, but it is quickly modified by the Indian Ocean. This airstream seldom passes south of 5° N.

West China Trough. The Asiatic high tends to form two ridges—one pointing southeastward to the Chinese coast and Taiwan, the other stretching southwestward along the eastern Indian coast and merging with the Indian high. Between these two ridges lies the broad west China trough, stretching from central Myanmar to southwestern China. The Tibetan Plateau's lee side effects intensify this trough. With the India-Myanmar trough, it defines the breaking point between the southern (or Indian) and southeast Asian monsoons. Active cold surges often occur when this trough is weak.

Australian Heat Low. This low develops during the Southern Hemisphere summer. It strengthens the northeast monsoon by increasing the pressure gradient between Asia and Australia. Its mean January position is 17° S, 135° E with a mean pressure of 1,006 mb (see Figure 2-4a).

Asiatic (or Pakistani Heat) Low. From May to early October, this low anchors the eastern end of a broad, low-level thermal trough extending from northwestern India across southern Pakistan, Iran, Saudi Arabia, and into the Sahara. This normally cloud-free low is strongest in July, when its central pressure averages 994 mb. Its mean position in July is near 35° N, 65° E (see Figure 2-4c). This thermal low draws in the NETWC, anchoring its western end. Flow around the Tibetan Plateau dynamically enhances the troughing in India.

Thailand Heat Lows. These lows are a series of heat lows that develop over western Thailand and Myanmar from May through early July (see Figure 2-7). Spring's increasing insolation and the cloudless skies of the northeast monsoon lead to formation of the Thailand lows. Land/sea breezes are particularly pronounced when these lows are strong. As the southwest monsoon strengthens, Thailand lows gradually move northward into southern China.

India-Myanmar Trough. This quasi-stationary trough develops in the summer along 85° E in the lee of the Tibetan Plateau. Figure 2-7 shows the trough's mean position during the southwest monsoon. It combines with the west China trough to define the breakpoint between the southern (or Indian) and southeast Asian monsoons. The trough strengthens the tropical easterly jet (TEJ) over the Bay of Bengal and is a preferred area for the development of monsoon depressions.

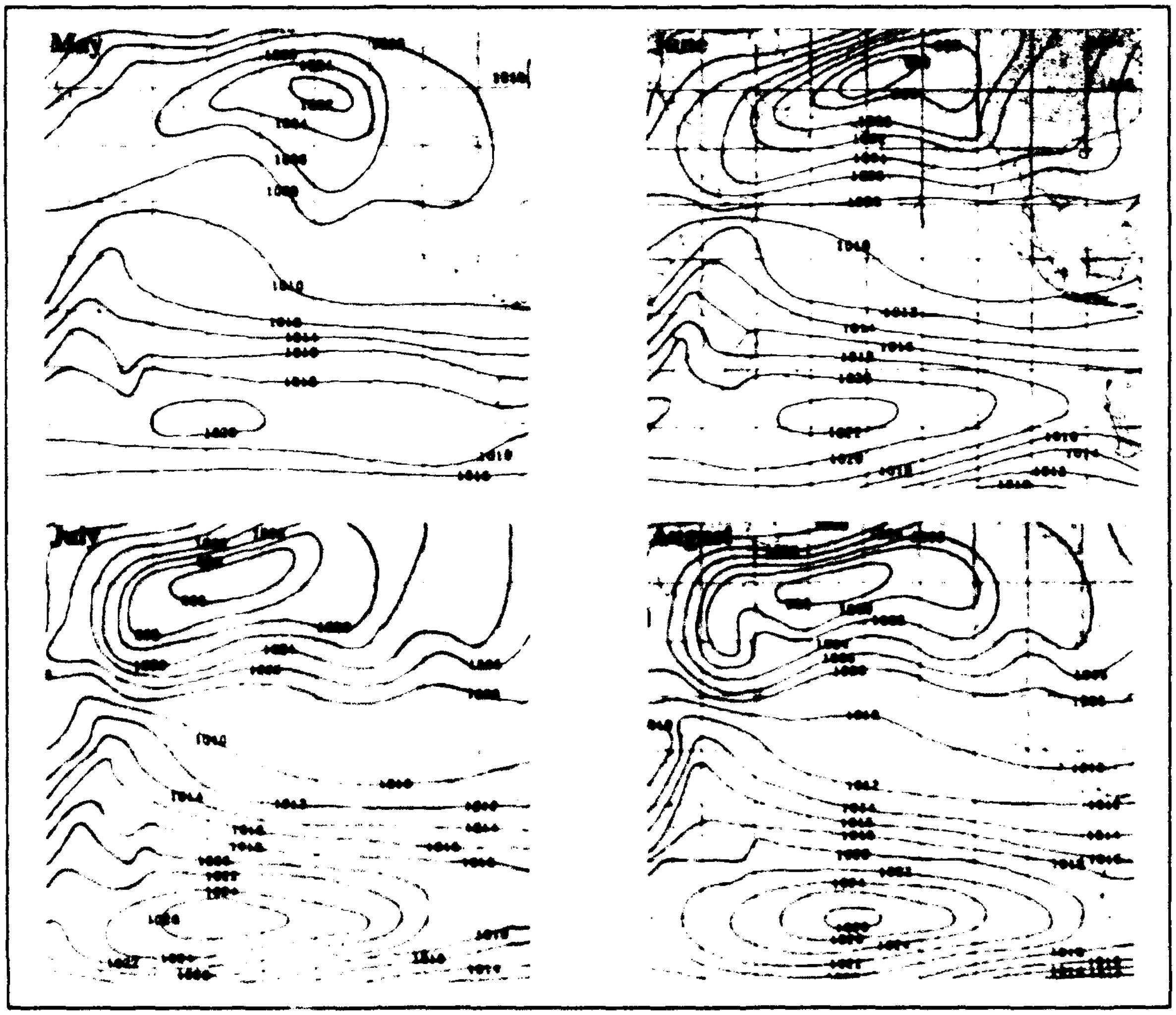


Figure 2-7. Monthly Mean Sea-Level Pressure Charts for May through August. The figure shows the Thailand heat low and the Indian-Myanmar trough (Gadgil, 1977)

Monsoon Climate. During the Northern Hemisphere winter, the warm oceanic ridge and the Asiatic high form a continuous belt of high pressure. In summer, heat lows replace the Asiatic high. This seasonal reversal of the pressure gradient gives rise to the northeast and southwest monsoons that affect southeast Asia. The term "monsoon" (from the Arabic "mawsim" or "season") is commonly applied to those areas of the world where there is a seasonal reversal of prevailing winds, but the generally accepted definition of a monsoon climate includes satisfaction of these four criteria:

- The prevailing seasonal wind direction shifts by at least 120 degrees between January and July,

- Wind speeds must equal or exceed 6 knots (3 m/s) at least one of the two seasons,

- Fewer than one cyclone-anticyclone alternation occurs every 2 years in either month in a 250 x 250 NM (500 x 500 km) square.

Near Equatorial Tradewind Convergence (NETWC). The NETWC (specifically the northern NETWC, as described on the following page) marks the dividing line between the winds of the northeast and southwest monsoon (see Figure 2-8). Previously known as the intertropical convergence zone (ITCZ) and the meteorological equator, the NETWC is caused by the convergence of the outflows from the Northern and Southern Hemispheres' subtropical highs. Southeast Asia's NETWC is split by the outflow from the southern Indian Ocean high and winter's Asiatic high. The slopes of these boundaries are not uniform with height, but fluctuate with small changes in density and wind speed.

- ***Northern NETWC.*** The northern NETWC exists year-round between the trade winds and the equatorial westerlies in the Indian Ocean. It is produced by convergence of the outflows from the North Pacific high and the southern Indian Ocean high. The trough is evident up to 300 mb.

The northern NETWC follows the sun's annual movement, traveling north in the Northern

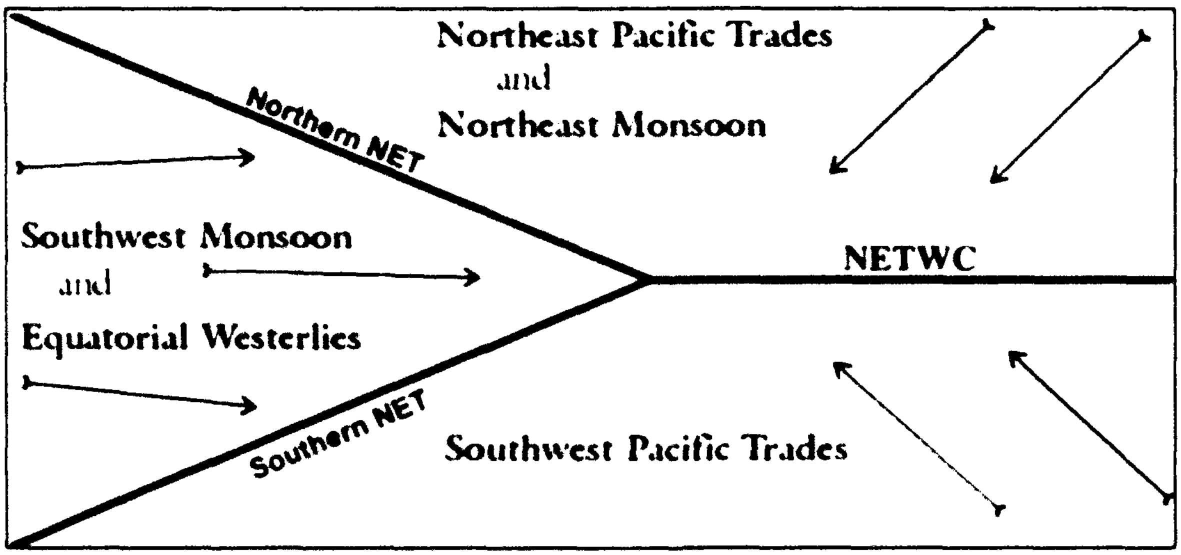


Figure 2-8. Schematic Representation of the NETWC over Southeast Asia (Watts, 1955). Figure shows relationship between monsoonal flow and trade winds in the formation of the NETWC

Hemisphere summer and returning south during winter, but it trails the sun's migration by about 6 weeks. Its northward movement is more gradual than its southward movement. From March to May, as low-pressure systems temporarily weaken the Asiatic high, the northern NETWC moves gradually northward in brief 1- to 3-day surges. Northward shifts are usually about 90 km each, but the NETWC has moved as much as 150 km in 24 hours. Surges are strong during March since the Asiatic high is still strong, but the surges become much weaker and more variable in April and May. The northern NETWC reaches its northernmost extent by the end of May or early June. Between July and September, the eastern end of the northern NETWC is pulled into the Asiatic heat low, and its position becomes indeterminate over land.

The northern NETWC retreats southward during the fall, marking the onset of southeast Asia's northeast monsoon. During the northeast monsoon, the NETWC sometimes becomes active as weak disturbances pass westward along it, bringing rainfall to areas south of 10° N. This rainfall can be heavy and continuous; Ranong, Thailand, (10° N, 99° E) received more than 450 mm of rain in a single day from one of these disturbances. These disturbances can become coupled with eastward-moving disturbances along the subtropical jet, creating broad areas of rainy weather. This phenomenon causes Singapore and Malaysia to experience their wet season from December through February.

• ***Southern NETWC.*** The southern NETWC forms during the Northern Hemisphere summer between the outflows from the Indian Ocean high and the Australian high. This trough keeps the Malay Peninsula rainy during the southwest monsoon, even though the northern NETWC is far to the north. The strength of the southern NETWC seems to vary inversely with that of the northern NETWC (when one is strong, the other is weak). The southern NETWC tends to oscillate between two positions, one near 2° N and the other near 5° S.

When active, these NETWCs are evident on streamline charts as a series of quasi-stationary vortices or closed lows. These lows tend to form on the leeward side of hills or over areas of high temperatures. Although their movements usually generate heavy convection and rainfall, the specific weather they produce is very sensitive to changes in the boundary's slope. There is rarely a continuous line of clouds and precipitation along the NETWC axis.

Possibly originating from disturbances in the trades, convergence zones or vortices within the NETWC control convection. When strong, these vortices extend up to 500 mb. The Annam Mountains and the mountains on the Malay Peninsula and Borneo help form the convergence zones by turning the northeasterly flow cyclonically. Figure 2-9 shows the precipitation associated with vortices along the northern and southern NETWCs. These patterns move westward within the NETWC boundaries.

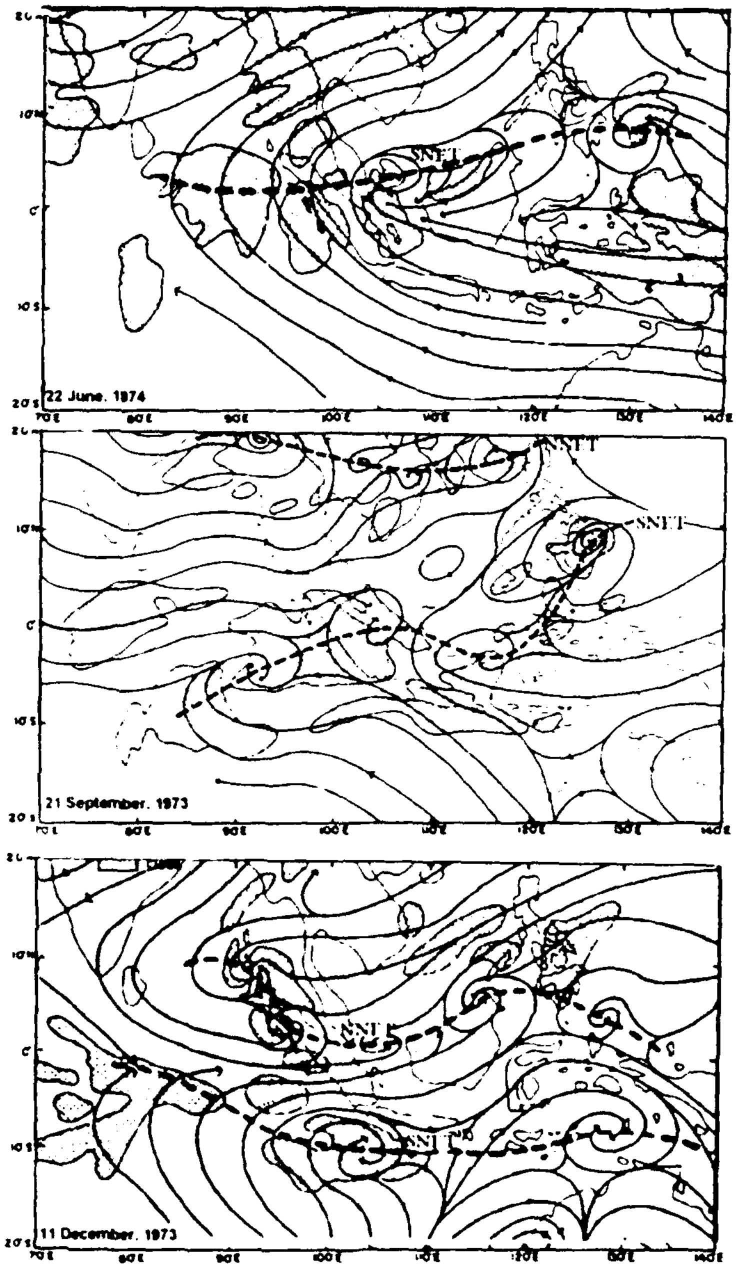


Figure 2-9. Surface Streamline Charts Showing Vortices and Precipitation along the NETWC (Chen and Choon, 1988). Precipitation is indicated by the shaded areas.

Figure 2-10 shows the northern NETWC's mean monthly position (heavy line) over southeast Asia. The southern NETWC's mean position is south of the region, though a small portion of it can be seen near the Malay Peninsula in the figure for July. The northern NETWC's position on any given day may differ greatly from these mean positions, especially during the transition seasons. Its position over land is often indeterminate during the summer.

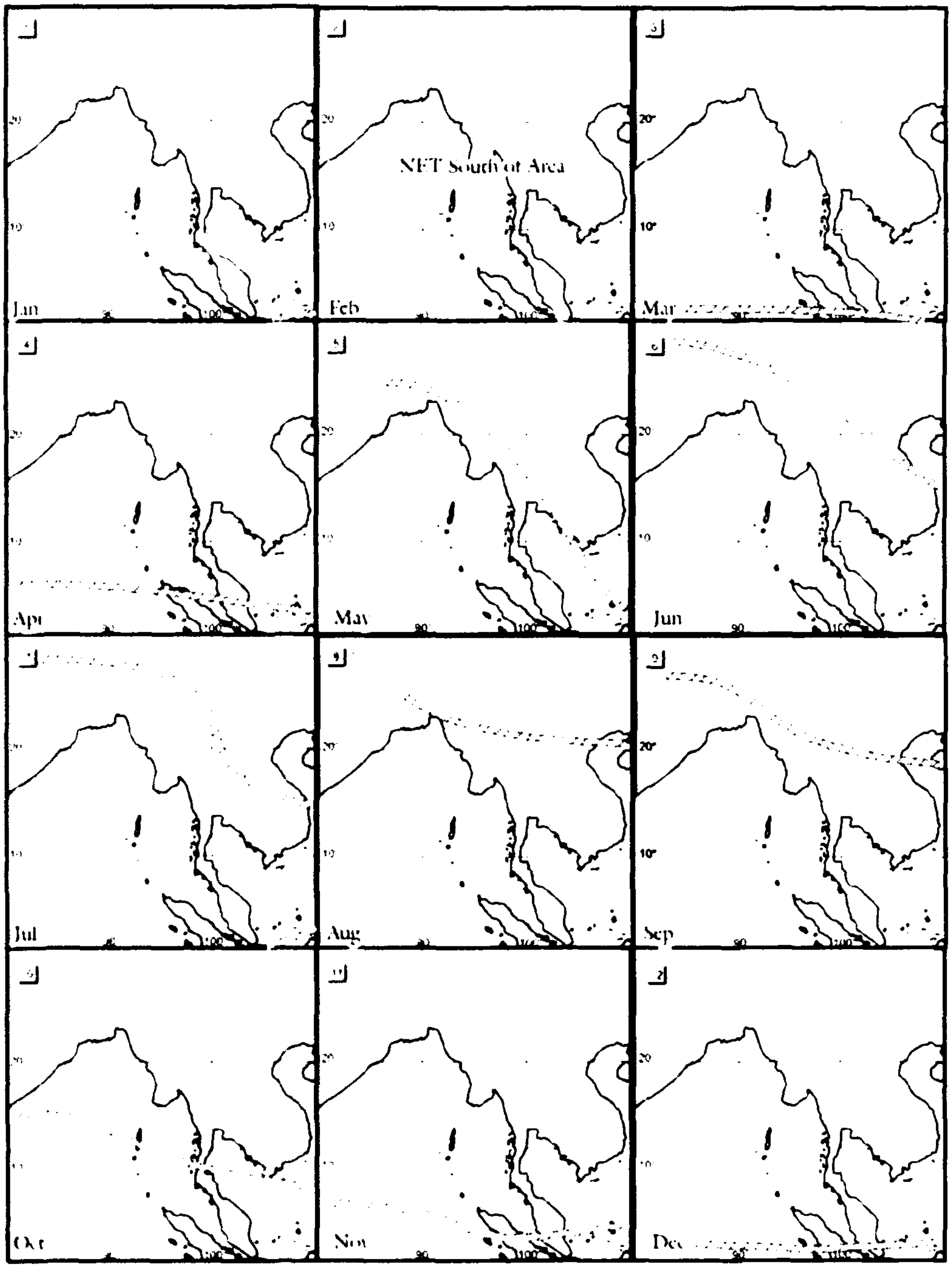


Figure 2-10. Monthly Mean Position of the NETWC over Southeast Asia. The figure shows the annual migration of the NETWC over southeast Asia.

The Northeast Monsoon. This monsoon occurs when the northern NETWC (NNET) migrates to the south during the Northern Hemisphere summer, allowing outflow from the Asiatic and North Pacific highs to cross the region. Stable weather and relatively cool northeasterly winds typify the northeast monsoon. The Tibetan Plateau blocks the direct flow of cold air from the Asiatic high, but the air funnels through the mountain ranges east of Myanmar. The northeast monsoon is also characterized by a succession of cold air surges that sometimes reach as far south as Singapore; surface winds accompanying these surges often exceed 30 knots. Figure 2-11 shows the usual positions of the polar front and NNET during the northeast monsoon. Figure 2-12 shows a cross section of the wind flow during the northeast monsoon.

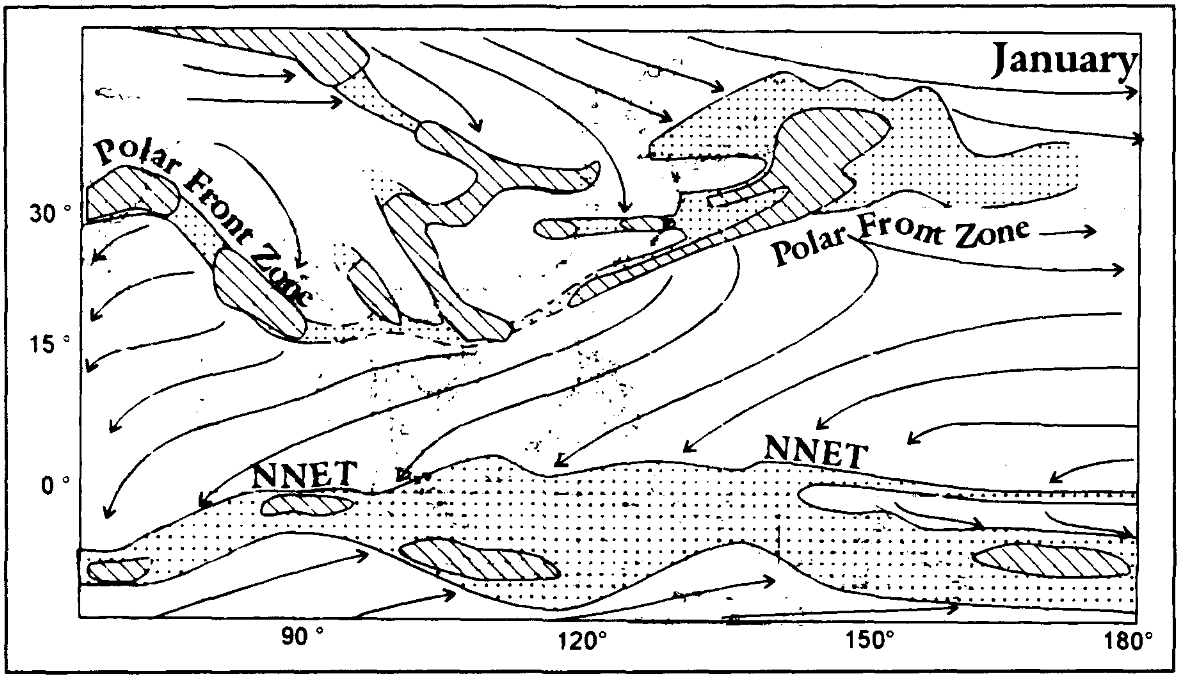


Figure 2-11. January NETWC and Polar Frontal Zones (Yoshino, 1971). Arrows indicate the mean wind flow direction; stippled and hatched areas show where the wind direction is more variable.

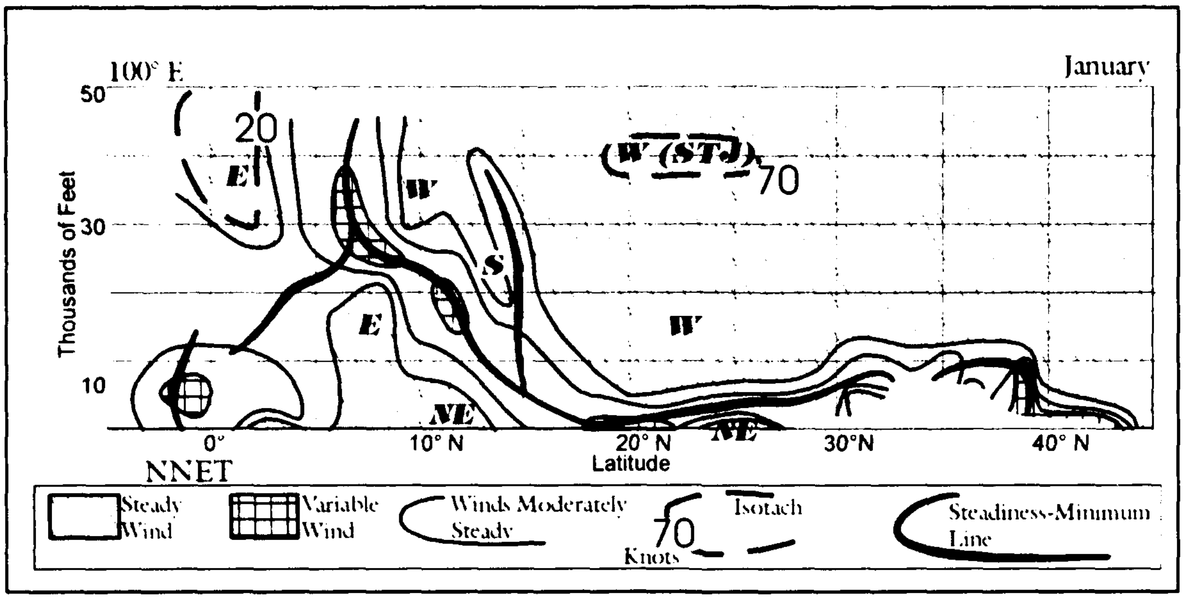


Figure 2-12. Vertical Cross Section along 100° E, January (Yoshino, 1971). Striped areas show regions where the wind direction is very steady. Crosshatched areas show where the wind direction is variable, indicating a shear zone. Regions where the wind direction is least steady, which can be interpreted as frontal zones or the NETWC, are shown as heavy lines. Selected isotachs are shown as dashed lines. Early in the season, the easterly flow is deepest south of 25° N.

Rainfall is scarce during the northeast monsoon, except over the southern Malay Peninsula and the windward mountains of Vietnam. The Malay Peninsula continues to receive almost daily rainshowers during the northeast monsoon, although accumulations diminish after December as substantial cross-equatorial flow from the Australian heat low causes increased subsidence. South of 10° N, northeast monsoon flow turns to become Indonesia's and Australia's northwest monsoon.

The onset of the northeast monsoon is often abrupt, beginning in the north in October and moving irregularly southward. It starts when the subtropical ridge aloft moves southward, allowing mid-latitude disturbances into the region. Southern China's 200-mb winds switch from easterly to westerly with the onset of the monsoon; Malaysian forecasters consider this the primary indicator of the onset of the northeast monsoon. The monsoon boundary is occasionally marked by widespread, heavy rainfall, especially on the east coast of the Malay Peninsula. The northeast monsoon is well-established throughout the region by mid-December. Typhoons and other tropical disturbances are still possible, but by January only weak remnants affect the area.

The northeast monsoon ends in March/April (in the south) or May (farther north) as the NETWC again moves northward. The subtropical jet moves north of the Tibetan Plateau, and the Tibetan high and the tropical easterly jet become established. In Malaysia, this has come as early as 5 February and as late as 31 March.

The Southwest Monsoon. This monsoon begins in the south in March, progressing northward through May as the northeast monsoon weakens and the NETWC moves north. This progress is much more gradual than the northeast monsoon's advance, and the NETWC sometimes retreats southward for short periods. The monsoon reaches about 22° N, its northernmost extent, by the end of May. Except where terrain causes a rain-shadow effect, rainfall gradually increases as the monsoon advances.

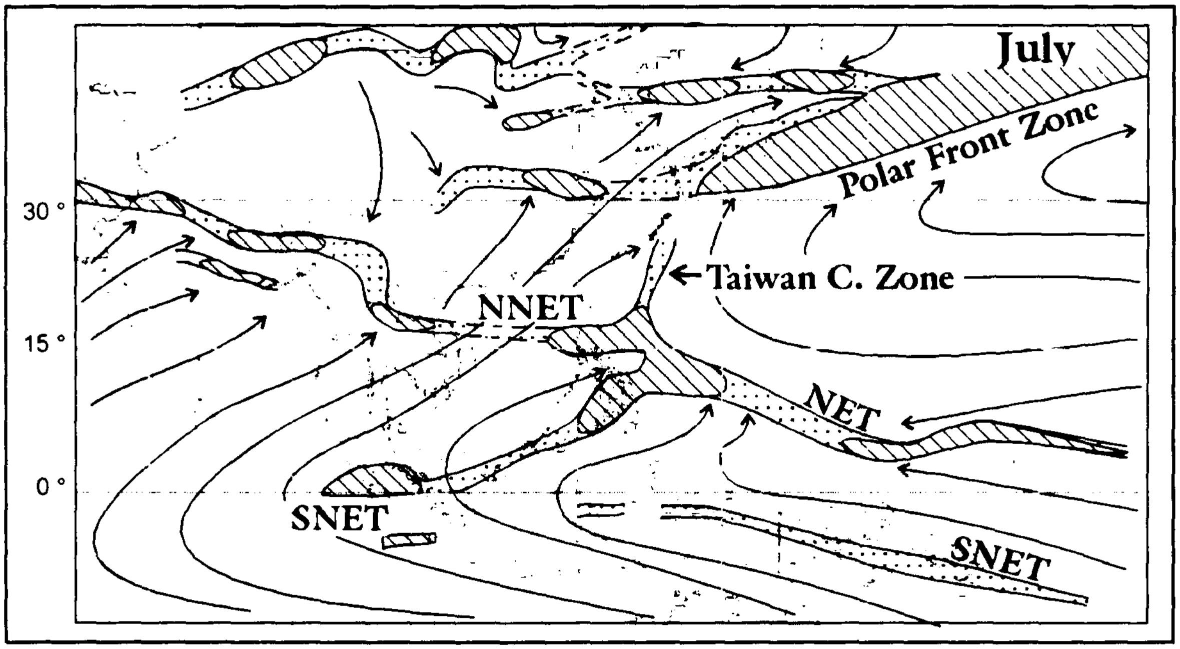


Figure 2-13. July NETWC Zones (Yoshino, 1971). Arrows indicate wind flow direction; stippled and hatched areas show where the wind direction is more variable. Arrows represent very steady winds.

The southwesterly flow originates from the south Indian Ocean high and receives increased impetus from the Somali jet. Figure 2-13 shows the preferred positions of the NETWC during the southwest monsoon. The southern NETWC's (SNET) two preferred positions are visible in Figures 2-13 and 2-14. Figure 2-14 provides a cross section showing mean wind flow during the southwest monsoon. The top of the southwest monsoon layer is usually near 500 mb, with flow from the subtropical ridge evident at 200 mb. When the monsoon is strong, westerly winds extend above the 500-mb level.

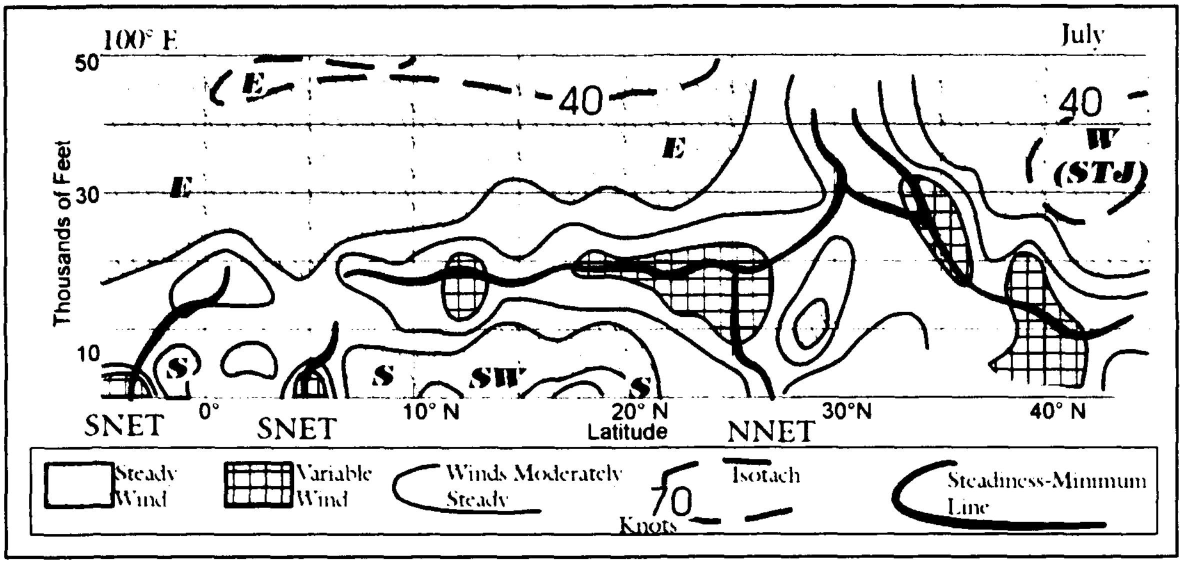


Figure 2-14. Vertical Cross Section along 100° E, July (Yoshino, 1971). Striped areas show regions where the wind direction is very steady; crosshatched areas show where the wind direction is variable, indicating a shear zone. Regions where the wind direction is least steady, which can be interpreted as frontal zones or the NETWC, are shown as heavy lines. Selected isotachs are shown as dashed lines.

Conditions during the southwest monsoon are characterized by overcast skies, with nocturnal rain developing as nightly cooling of the cloud tops destabilizes the clouds. Most rainfall is from stratiform rather than convective clouds; in fact, there seems to be an inverse relationship between the number of convective showers over an area and the total amount of rainfall the area receives. Figure 2-15 shows a synoptic "model" of the southwest monsoon when the NETWC is over the region. Northern southeast Asia (areas marked with pattern A) experiences scattered, orographically-controlled convective clouds and widespread subsidence. Southern southeast Asia (pattern B) experiences multilayered stratiform clouds and only isolated convection. Precipitation is most widespread in southern southeast Asia, where synoptic-scale lifting enhances locally heavy rain. Thunderstorms are less frequent than in the north.

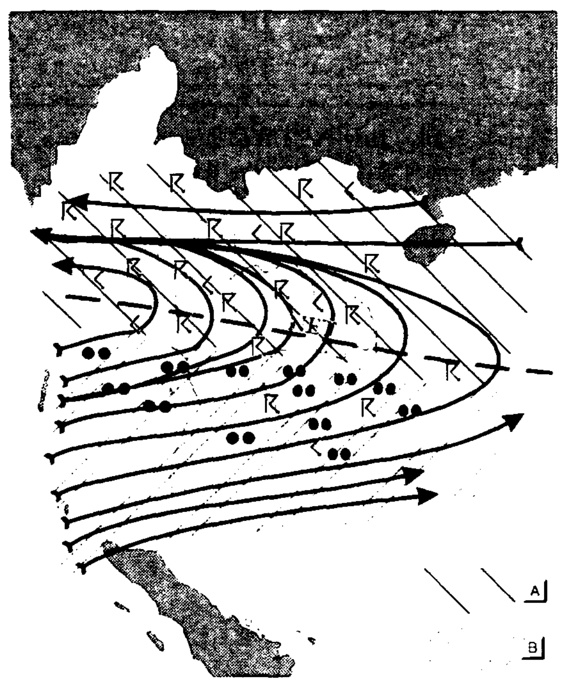


Figure 2-15. Rough Synoptic Model of the Southwest Monsoon (Harris, 1972). Conditions associated with "A" and "B" are described in the text.

Monsoon rains are not steady; diurnal and topographic variations in rainfall amounts and duration are considerable. The rains come in pulses that last from 2 to 10 days, followed by periods of calm weather. Rainfall is generally not associated

with small-scale disturbances, but with widespread changes that decrease stability over the entire region for several days. The rainy weather pattern does not move, but slowly decays as the synoptic conditions change.

Rainfall is concentrated on southwest-facing slopes below 2,000 meters, with the heaviest rainfall often occurring at 1,200 meters. Areas to the northeast of mountains receive the least rainfall due to the topography's rainshadow effect. In addition, southwest monsoon rains begin later in these areas than elsewhere. For example, Mandalay shows a decline in rainfall during June and July and does not receive monsoon rains until August.

Figure 2-16 is a satellite image showing the positions of both NETWCs and a strong polar front during the transition to the southwest monsoon. Several cyclonic vortices (indicated by "C") are evident along the NETWCs. North of the northern NETWC, cumuliform clouds with heavy rainshowers and thunderstorms are present. To its south, light, continuous rain and multilayered stratocumulus, altostratus, and cirrus are found. Trade wind cumulus is shown south of the southern NETWC.

Southwest monsoon flow is strongest from June to September. By late September the southwest monsoon winds become more southerly as the NETWC begins its southward march. By November, the southwest monsoon ends as the northeast monsoon pushes the NETWC beyond the region's southern boundaries.

Monsoon Breaks. These breaks occur when an equatorial anticyclone (sometimes called a buffer ridge) forms along the equator and migrates northward over southeast Asia. Figure 2-17 shows one of these anticyclones in the Gulf of Thailand. When the break is severe, it is evident at 500 mb as a ridge intruding from the North Pacific high. During monsoon breaks, the nocturnal rain pattern

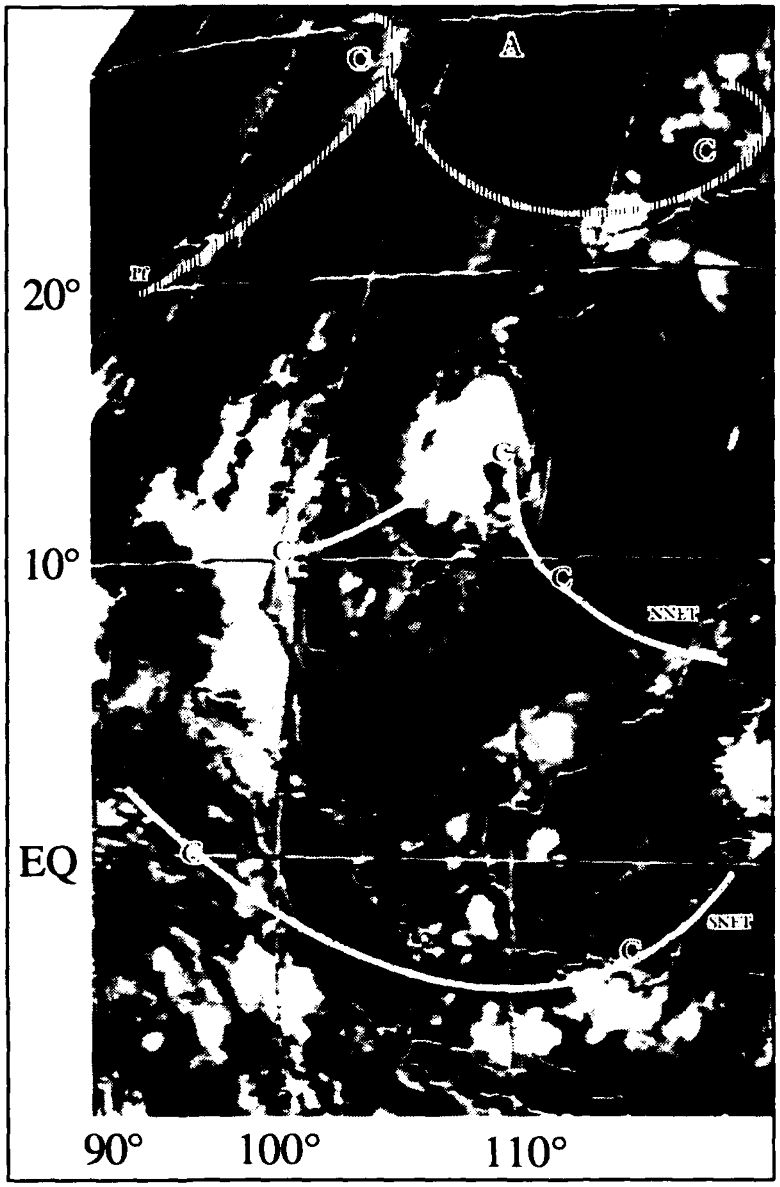


Figure 2-16. GMS IR Image, 03Z, 4 May 1987. The figure shows NETWC and Polar Front Positions (NOAA/NESDIS).

ceases. The decreased cloud cover leads to increased surface heating, causing afternoon and evening thunderstorms. Strong convective instability is evident, but convective activity is suppressed by large-scale subsidence. During the break, surface winds are weak, westerlies are shallow, and the tropical easterlies tend to shift northward. A severe monsoon break causes droughts and subsequent famines. The break ends when a trough moves southward, shifting the ridge eastward.

The ridge from the 500-mb high seldom extends to Myanmar. Over Myanmar, breaks occur most frequently in September when the southwest monsoon begins to weaken and the Tibetan anticyclone is away from its normal position. A transitory high formed in response to a strong polar front to the north can also cause a break in the monsoon over Myanmar.

Figure 2-18 shows morning and afternoon satellite images during a monsoon break. Note the almost total lack of clouds over southeast Asia in the morning, but the widespread thunderstorm development in the afternoon. Typhoon Vernon is evident northeast of the Philippines, and a monsoon

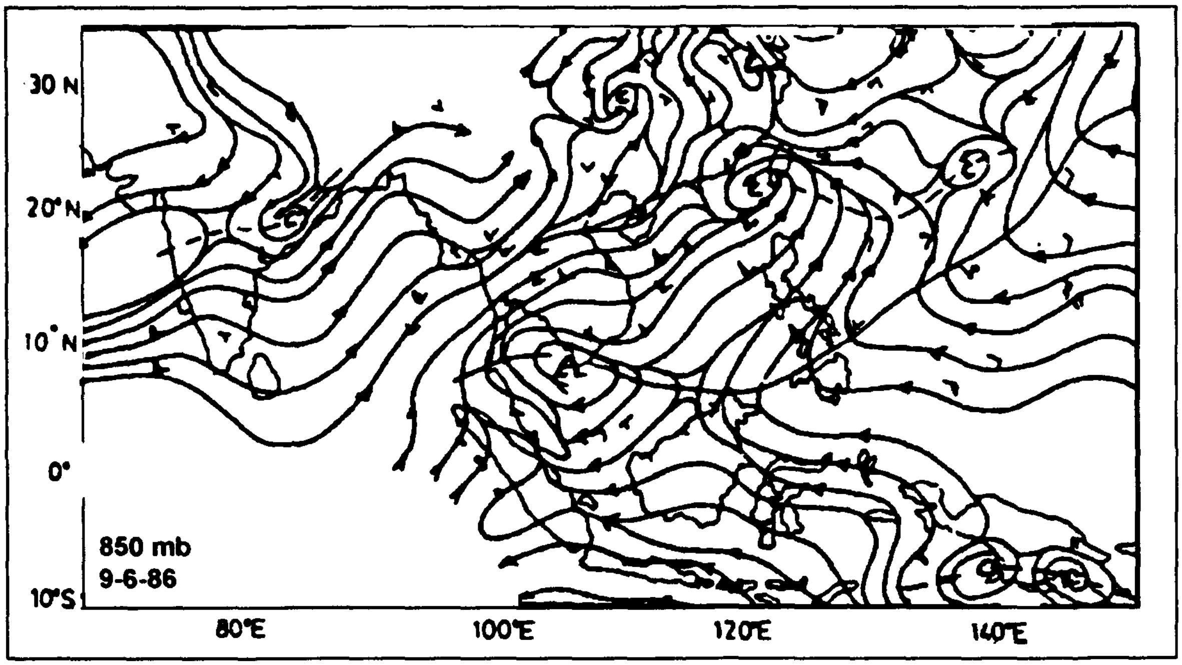


Figure 2-17. 850-mb Streamline Analysis, 9 June 1986 (Cheang and Tan, 1988). The "A" in the Gulf of Thailand indicates a monsoon break.

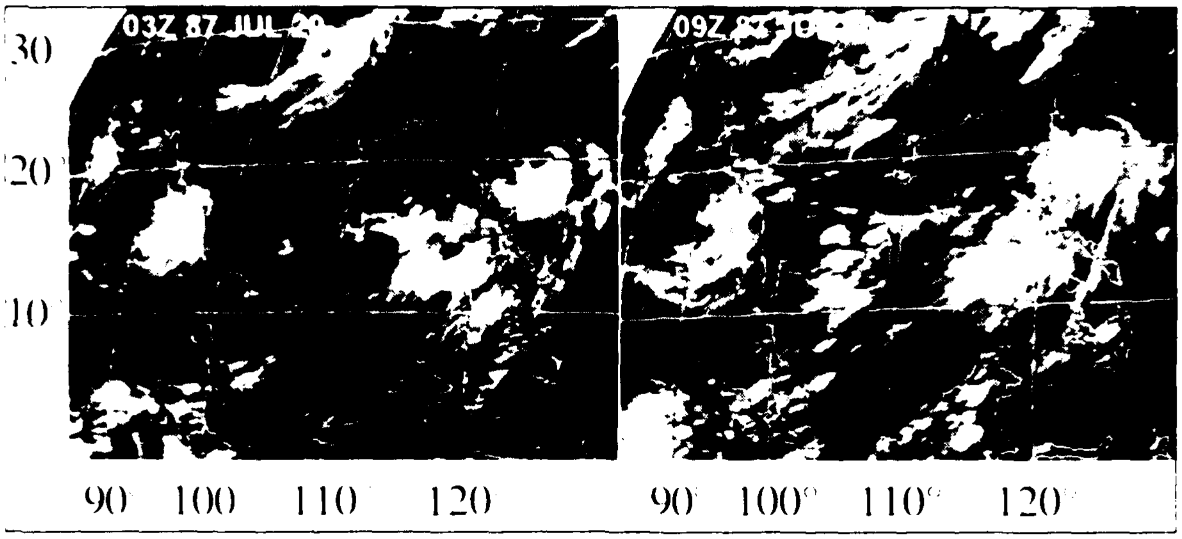


Figure 2-18. GMS IR Images 03Z (left, morning) and 09Z (right, afternoon) 20 July 1987 (NOAA/NESDIS). The figure highlights the development of convective activity (over southeast Asia) associated with heating during a monsoonal break.

depression from the Bay of Bengal is moving into Myanmar. These are typical conditions during a monsoon break.

During monsoon breaks, Malaysia's rainfall pattern is often reversed from that of the rest of southeast Asia, and Malaysia actually receives more rain than during an active southwest monsoon. This is because the Malay Peninsula lies on the lee side of Sumatra's mountain range when southwesterly flow prevails. During breaks, however, synoptic flow is weakened and winds become more southerly or easterly, and Malaysia no longer lies in the lee of the flow over Sumatra. Thus, convective activity is able to develop.

Trade Wind Inversions. The subtropical highs slope toward the equator with height, producing a subsidence inversion over the trade winds. During intense highs, relative humidity is greater than 70 percent below the inversion, but less than 50 percent above. The inversion produces stable conditions, preventing precipitation by trapping moisture in the lower layers of the atmosphere and capping cumulus development. The inversion west of the North Pacific high is weaker and less persistent than the one to the east. Warm waters further weaken or cancel the inversion over the South China Sea. In January, the inversion is confined to north of 16° N, and it extends to 700 mb. This coincides with the limit of extensive stratus along the Vietnamese coast.

Equatorial Westerlies. This band of westerly winds separates the northern and southern NETWCs (see Figure 2-19). Formed by outflow from the South Indian Ocean high, the equatorial westerlies begin along the African coast and extend eastward to 130° E. In summer, these winds are strengthened near 110° E by outflow from the Australian high. Westerly flow extends from the surface to 700 mb, but in July, its strongest month, it extends to 500 mb. The equatorial westerlies provide a source of cool, subsiding air between the northern and southern monsoon boundaries. Eastward-moving waves form in this flow.

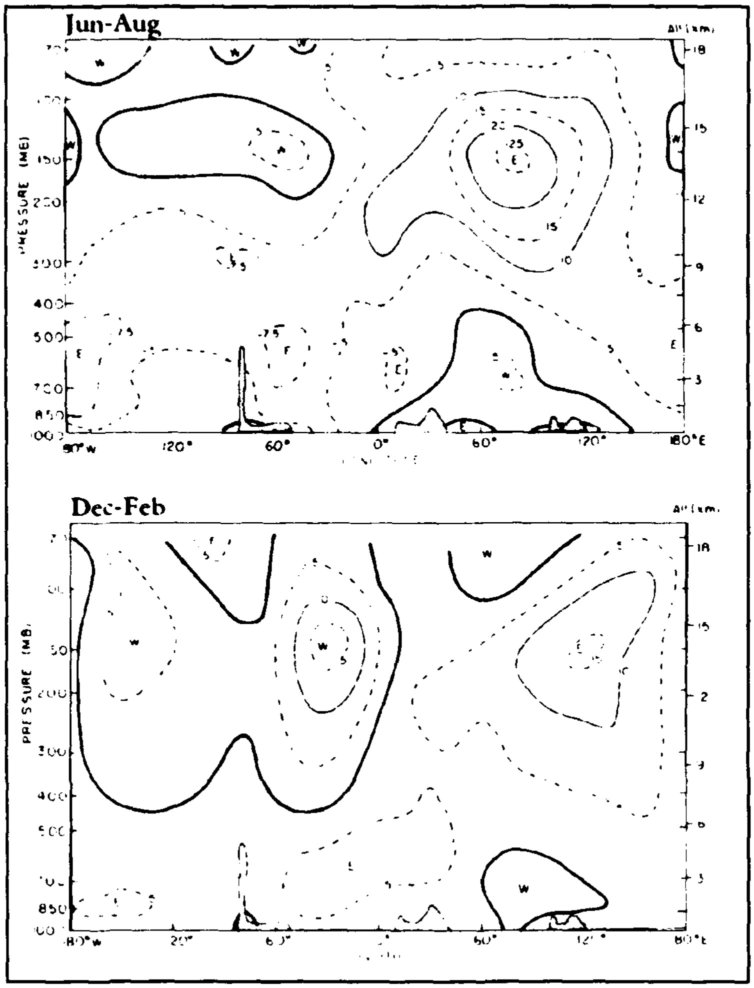


Figure 2-19. Cross Section along the Equator (Newell, et al., 1972).
The figure shows equatorial westerlies. Isotachs are in knots.

Jet Streams. Four primary jet streams affect this region: the subtropical jet (STJ), the tropical easterly jet (TEJ), the Northern Hemisphere mid-tropospheric easterly jet (MTEJ), and the tropical low-level jets. These are described below.

Subtropical Jet. This is the southerly branch of the mid-latitude westerlies. (The northerly branch, the polar jet, lies between 45° and 70° N and rarely affects southeast Asia directly.) In winter, the STJ stretches from just south of the Tibetan Plateau across the Yangtze Valley and over southern Japan. In summer, the STJ moves north of the Tibetan plateau. Figure 2-20 shows the STJ's mean position during January, April, July, and October. The mean height of the STJ is near 12 km; its mean speed is 65 knots in January and 45 knots in July.

The STJ provides upper-level steering, shear, and outflow. Rainfall is often concentrated along the jet axis. Occasionally, the STJ pushes as far south as 10° N, and while the accompanying cold surge does not cause widespread rainfall over Malaysia, it does signal more frequent tropical storm development in the region.

The STJ rejoins the polar jet near southern Japan. The strength of the jet in this region is a good indicator of the strength and characteristics of the North Pacific high. This confluence zone, shown in Figure 2-21, sometimes extends southwestward through China and into northern Myanmar. The area of confluence occasionally enhances cyclogenesis in the South China Sea. The overall effect of the two rivers of fast-moving air merging into one deep, faster layer enhances upper-level divergence. This causes low-pressure systems in the area to deepen quickly.

Although the STJ shows less variability in its daily position (2-3 degrees of latitude), its seasonal variability is greater than the polar jet's. By the end of May, the westerlies retreat north of the Tibetan Plateau—a prerequisite for the start of the southwest monsoon. Deformation of the wind flow around the mountains creates a distinct pattern, with the trough shifting from the Bay of Bengal to the Arabian Sea.

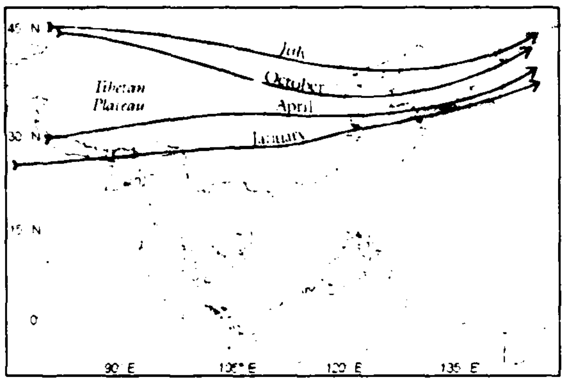


Figure 2-20. January, April, July and October Positions of the Subtropical Jet (Marcal, 1968). The figure shows the subtropical jet's migration northward followed by its retreat southward after July.

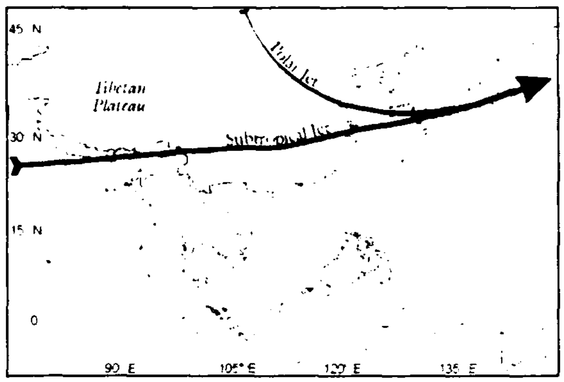


Figure 2-21. Convergence Zone of the Subtropical and Polar Jets (Yoshino and Urushibo, 1981). The figure shows the area of confluence associated with the convergence of jet streams near Japan.

Tropical Easterly Jet (TEJ). This Northern Hemisphere summer jet in the upper-level easterlies develops at or above 200 mb as outflow from the southern edges of the Tibetan anticyclone. Its mean position is across the Philippines westward to the Indian Ocean. It can be as far north as the South China Sea and as far east as Guam (about 140° E). This jet is strengthened over southeast Asia by the strong temperature contrast between the warm landmass and the relatively cool equatorial water.

The TEJ's mean position is near 15° N, 4 to 5 degrees south of the surface NETWC, but it oscillates between 5° and 20° N (see Figure 2-22). The strongest winds are found between 73° and 80° E, where maximum wind speeds reach 90 knots. The mean wind speed is about 60 knots. The jet position follows the highest sea-surface temperatures. Since a relatively cool area often develops in the South China Sea north of Borneo (see Figure 2-2, July), the TEJ sometimes splits into two axes near 5° and 20° N. Although the northern branch is stronger, it weakens when the South China Sea's low-level jet weakens.

The TEJ's position and intensity significantly impact southwest monsoon rains and low-level trade winds. The TEJ provides an outflow mechanism for NETWC convection. It causes upper-level divergence in the northern Bay of Bengal directly over the convergence provided by the NETWC. This provides a triggering mechanism for the development of monsoon depressions. Fluctuations in the TEJ's strength are connected to "pulses" in the monsoon flow.

Another band of upper-level easterlies is present year-round over southeast Asia, but the winds are too weak to represent a true jet. In February, the center of these easterlies reaches 10° S, with speeds averaging 35 knots. During the transition seasons, the center of the easterlies is near the equator, with

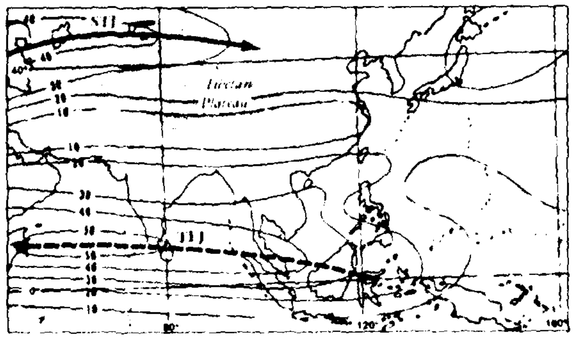


Figure 2-22. July Mean Position of the Tropical Easterly Jet, (Marcal, 1968). Wind speed in knots.

speeds averaging *10 to 20 knots. Even without jet*-stream strength, it carries pronounced wave disturbances.

Tropical Low-Level Jets. Three northward-flowing low-level jets form between May and October over the Indian Ocean and the South China Sea; their positions are shown in Figure 2-23. Entrance regions for these jets tend to be over warm sea areas. One jet develops in the equatorial South China Sea during the southwest monsoon and runs northeastward along the east coast of southeast Asia to about 20° N. Another jet develops in the Bay of Bengal near the equator at about 90° E and flows northeastward over the northwest Myanmar coast. The third jet, the Somali jet (also known as the east African jet) is the strongest of the three. It is active from April to late October, when flow from the South Indian Ocean high is compressed into a high-speed jet core along the eastern edge of Africa. The core normally passes just north of Madagascar heading to the northwest, enters Africa over southern Kenya, and turns to the northeast across Somalia. The core is usually at about 600 meters MSL over the Indian Ocean. Figure 2-24 shows the mean July monthly airflow at 900 meters across the western Indian Ocean basin.

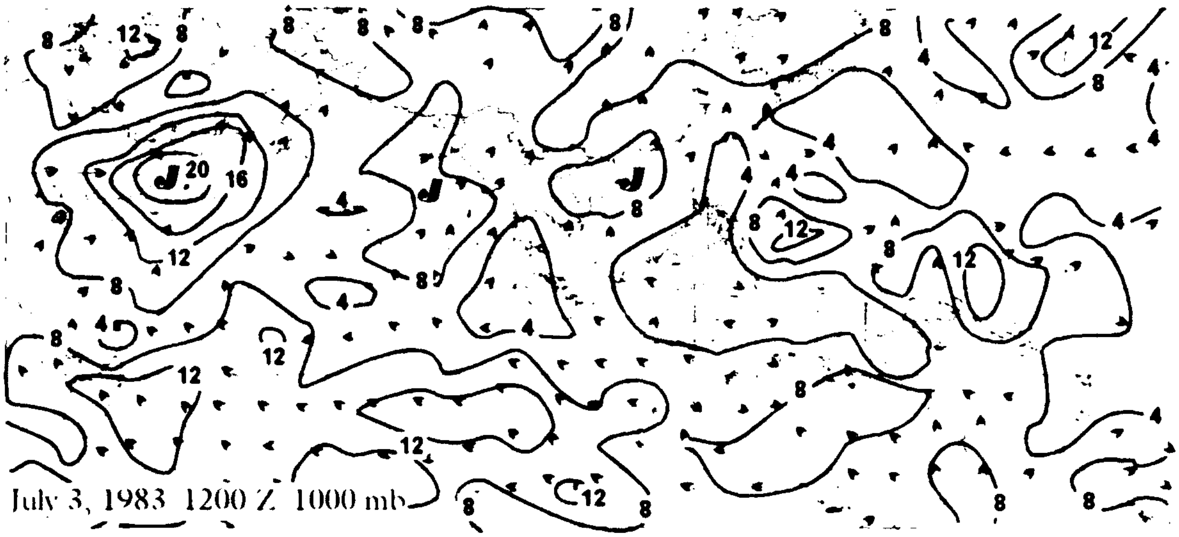


Figure 2-23. Mean Positions of the Low-Level Jets (Zhou, et al., 1990). Isotachs (knots) and arrows showing mean flow. Large "Js" show jet core positions.

The Somali jet has mean core speeds between 25 and 40 knots. The jet normally strengthens from April to July then gradually weakens from August to October. Highest speeds are found near the equator across Kenya and Somalia, where speeds of 100 knots have been reported. These extreme speeds may be related to Southern Hemisphere cold surges.

Like most low-level jets, the Somali jet shows a marked diurnal variation. Peak core speeds occur near dawn, and minimum core speeds occur in late afternoon. Surface wind speeds beneath the core are the opposite: minimum speeds occur at dawn; maximum speeds occur in midafternoon.

The Somali jet affects southeast Asia, 7,000 km away from its core, because it is the driving force of the equatorial westerlies. Periodic fluctuations in its strength are believed to be linked to surges in the monsoon flow.

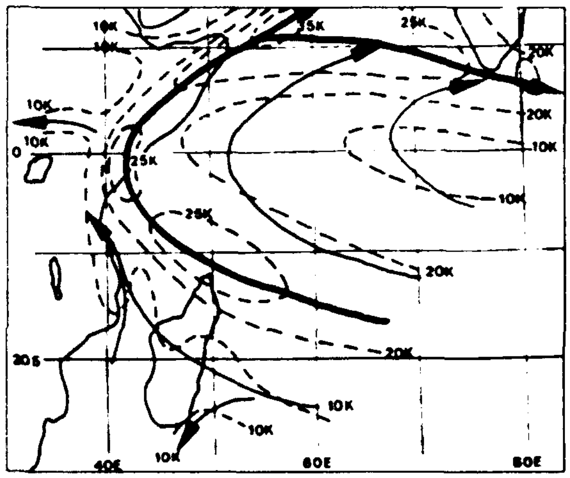


Figure 2-24. July Mean Monthly Airflow at 900 Meters. Solid lines are streamlines; dashed lines are isotachs in knots.

Mid- and Upper-Level Flow Patterns. Figures 2-25 through 2-28 show January, April, July, and October streamline flow at 850, 700, 500, and 200 mb. Some of the primary features are described below.

In January, 850-mb anticyclones are prominent along the southern Chinese coast, where they have moved from central China. Flow south of these highs pulls warm air from the Pacific into the area. The strong baroclinic zone in southern China causes the strong cold surges typical of the late northeast monsoon.

July's 500-mb pattern is complex because 500 mb is the transition level between the low-level southwest monsoon and the 200-mb tropical easterly jet. Vortices over northern southeast Asia indicate weak, indeterminate flow. A strong ridge from the North Pacific high causes easterly flow over northern Vietnam.

Flow patterns in the transition seasons (April and October) are generally weak, particularly in the lower levels, with wide variations as the NETWC migrates north and south. Interactions with the polar front and typhoons cause the NETWC's position and strength to vary significantly. A thermal low, evident in April at 850 mb in southwestern China, causes southerly flow, increasing convection in the interior of southeast Asia. In October, a thermal low forms over the still-warm waters of the Bay of Bengal, though it disappears by November.

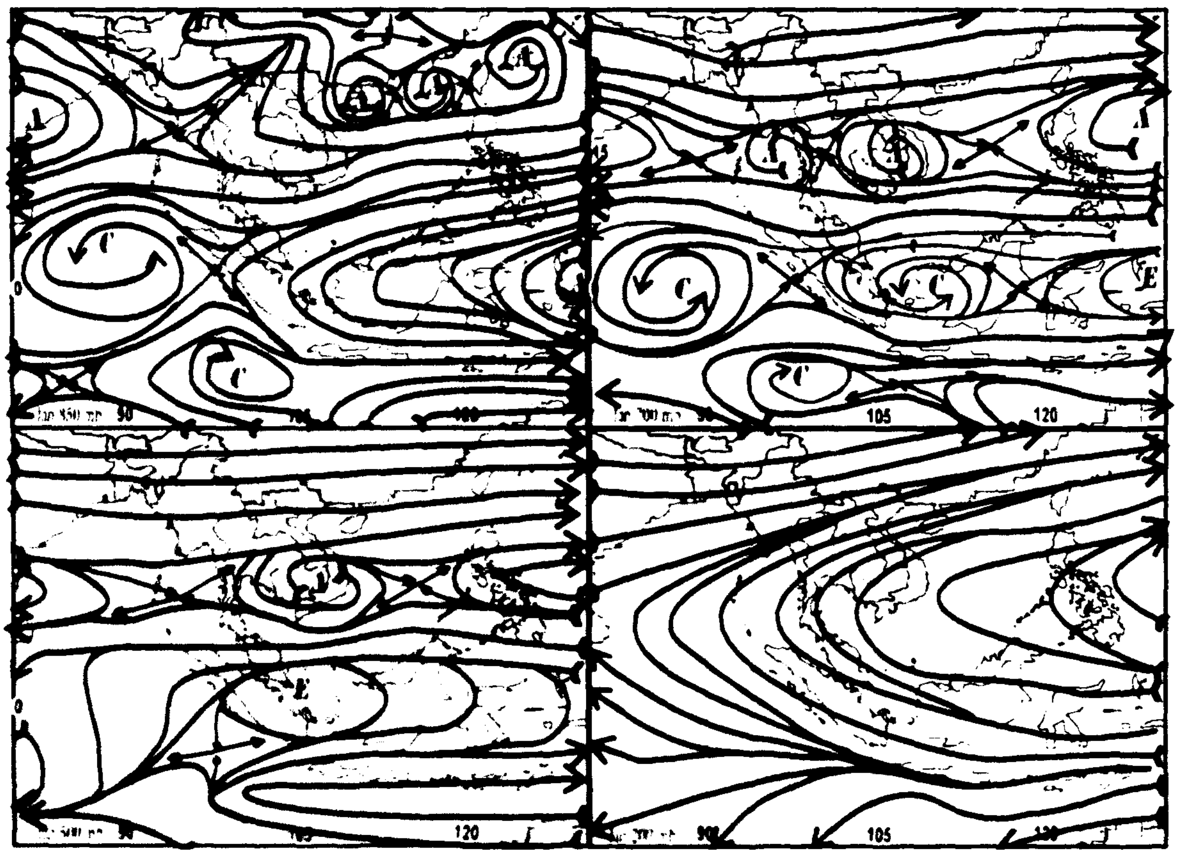


Figure 2-25. January 850-, 700-, 500-, and 200-mb Streamlines. The streamlines show the impact of pressure centers on general upper-air windflow.

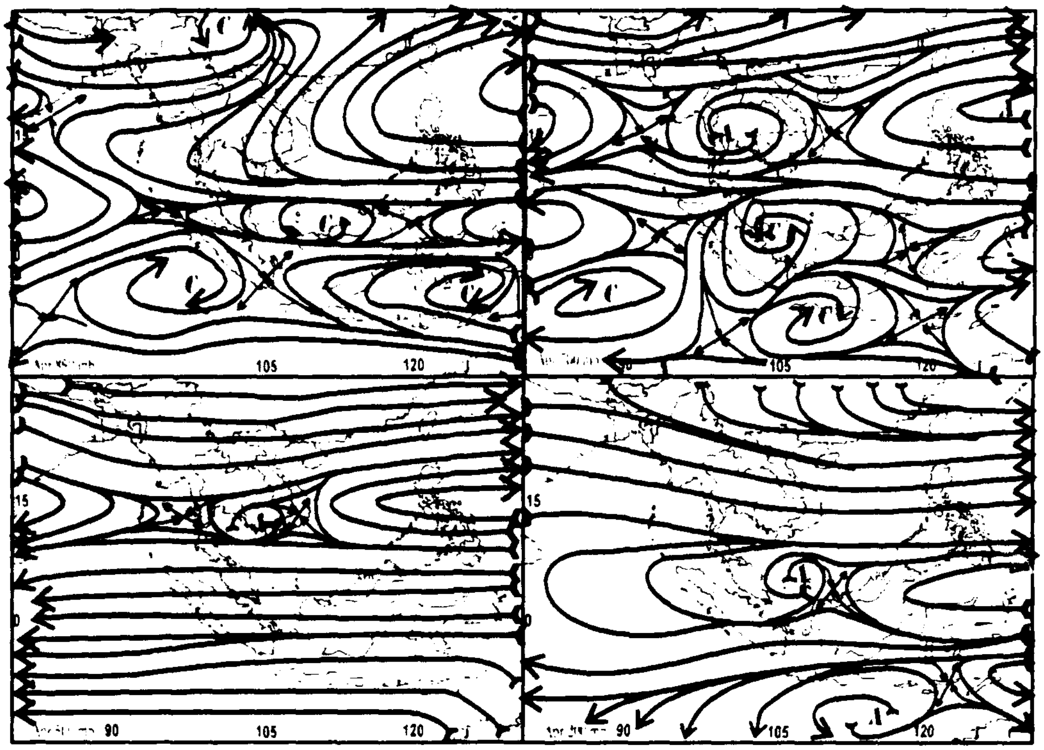


Figure 2-26. April 850-, 700-, 500-, and 200-mb Streamlines. The streamlines show the impact of pressure centers on general upper-air windflow.

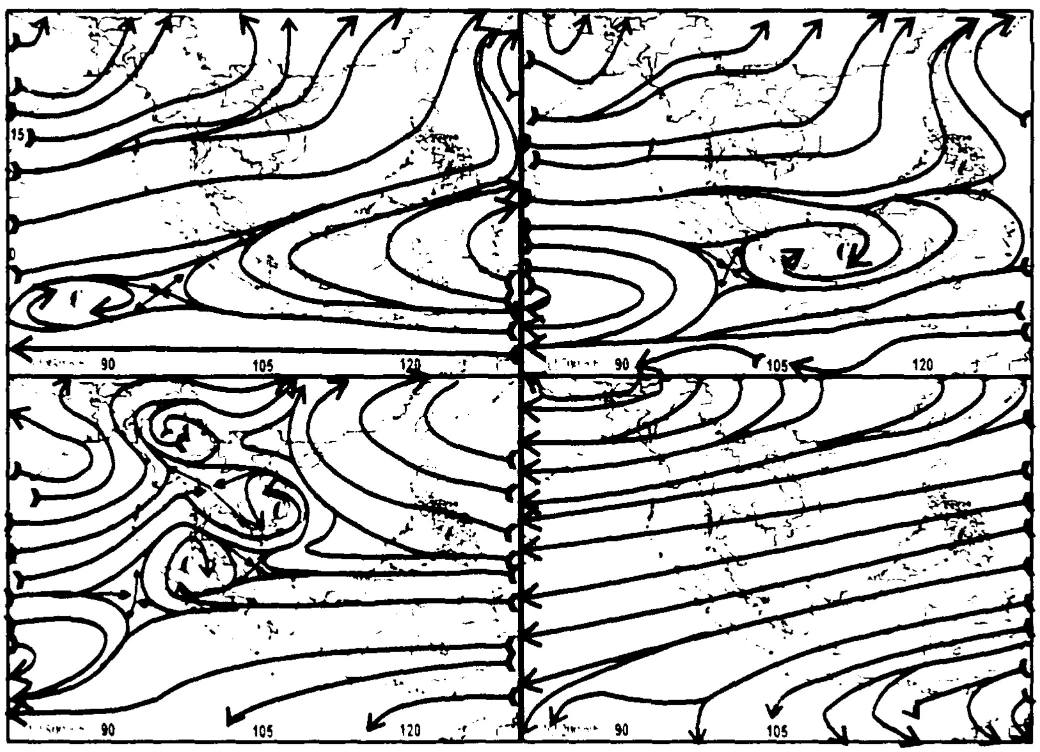


Figure 2-27. July 850-, 700-, 500-, and 200-mb Streamlines. The streamlines show the impact of pressure centers on general upper-air windflow.

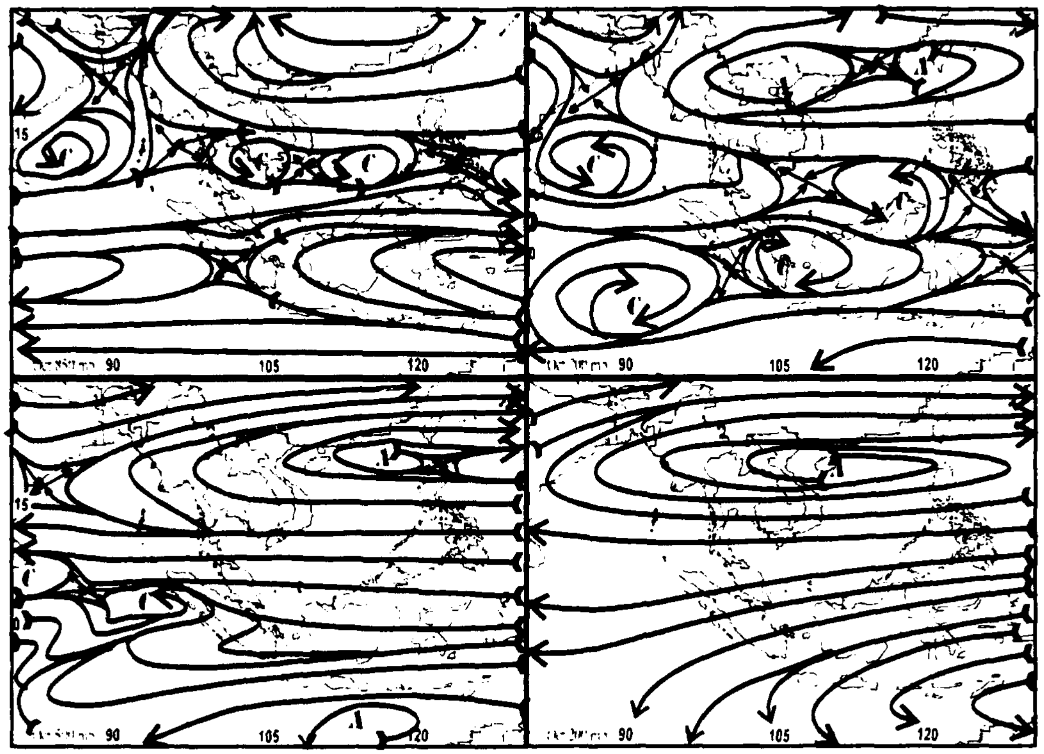


Figure 2-28. October 850-, 700-, 500-, and 200-mb Streamlines. The streamlines show the impact of pressure centers on general upper-air windflow.

Subtropical Ridges. These upper-level features are found north and south of the equator with easterly flow between them (see Figures 2-25 through 2-28 for the locations of the ridges at 200 mb). Their mean annual positions are 15° N and 10° S, centered at about 130° E. They move north-south with the sun and reach their northernmost positions (25° N) in January. These ridges provide outflow for convection from the NETWC and tropical cyclones. During the southwest monsoon, a northward shift of the subtropical ridge occurs every 2 or 3 years, bringing dry, dusty air to northern southeast Asia.

Subtropical ridges sometimes cause anticyclonic cells, such as the one shown at 200 mb in Figure 2-26, to form over southeast Asia. These cells are common enough to appear on some mean monthly 200-mb streamline analyses. The position and strength of these cells depend on the position and strength of the tropical upper-tropospheric trough (TUTT), described below.

Tropical Upper-Tropospheric Trough (TUTT). The TUTT is a buffer between two cells of the subtropical ridge. The TUTT enhances the upper-level divergence necessary for monsoon rains and acts as a triggering mechanism for typhoons. An inactive TUTT is oriented east-west, but an active TUTT is aligned northeast-southwest (see Figure 2-29) and is associated with extensive convection. During active periods, two TUTTs form in the Pacific.

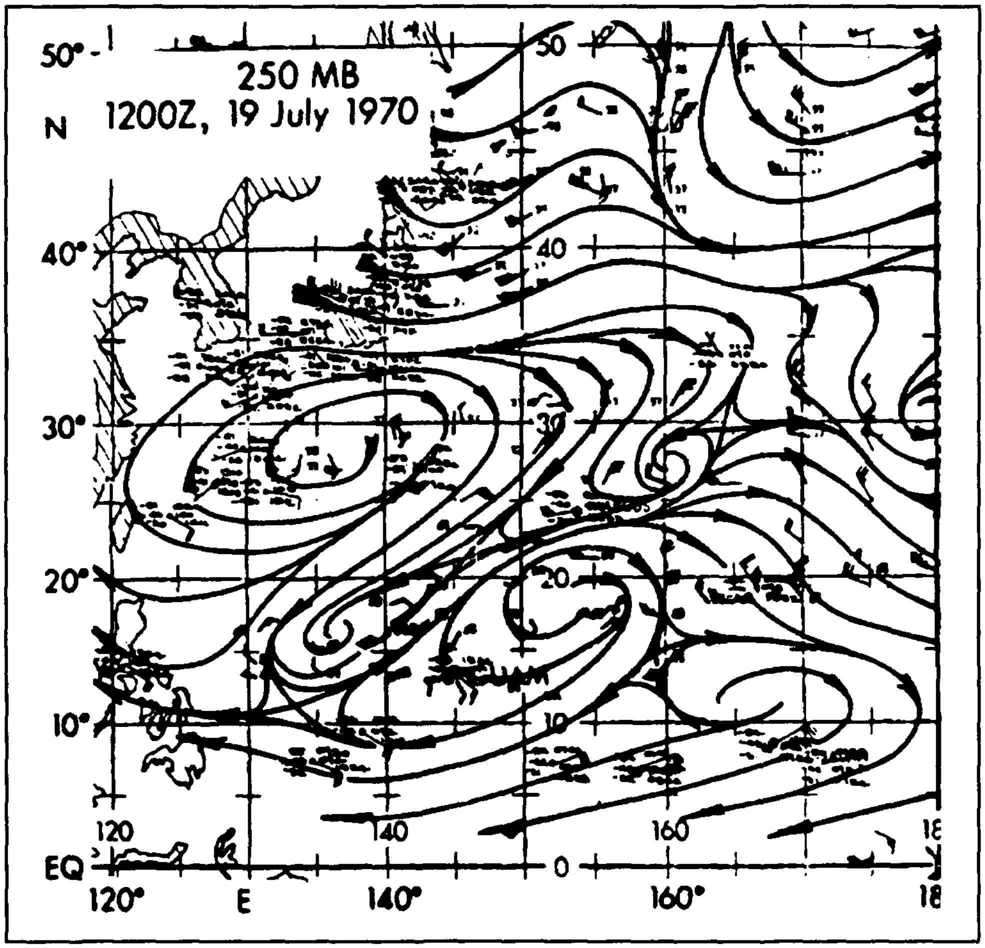


Figure 2-29. Streamline Analysis of the 250-mb Flow 12Z. The figure shows an active TUTT (Murakami, 1974).

Tibetan Anticyclone. This upper-level feature develops in April when a high-pressure cell from over southeast Asia migrates northwestward to the Tibetan Plateau. Figure 2-30 shows its mean position in May and July. At the plateau's surface (about 600 mb), a heat low forms and is surrounded by a ring of highs along the plateau's mountainous rim. The thermal low is sustained and deepened by intense heating of the plateau. As it strengthens, so does the upper-level anticyclone above it. The anticyclone also interacts with the subtropical ridge aloft. This interaction causes the Tibetan anticyclone's position to vary; if it shifts eastward of 90° E, a severe drought results.

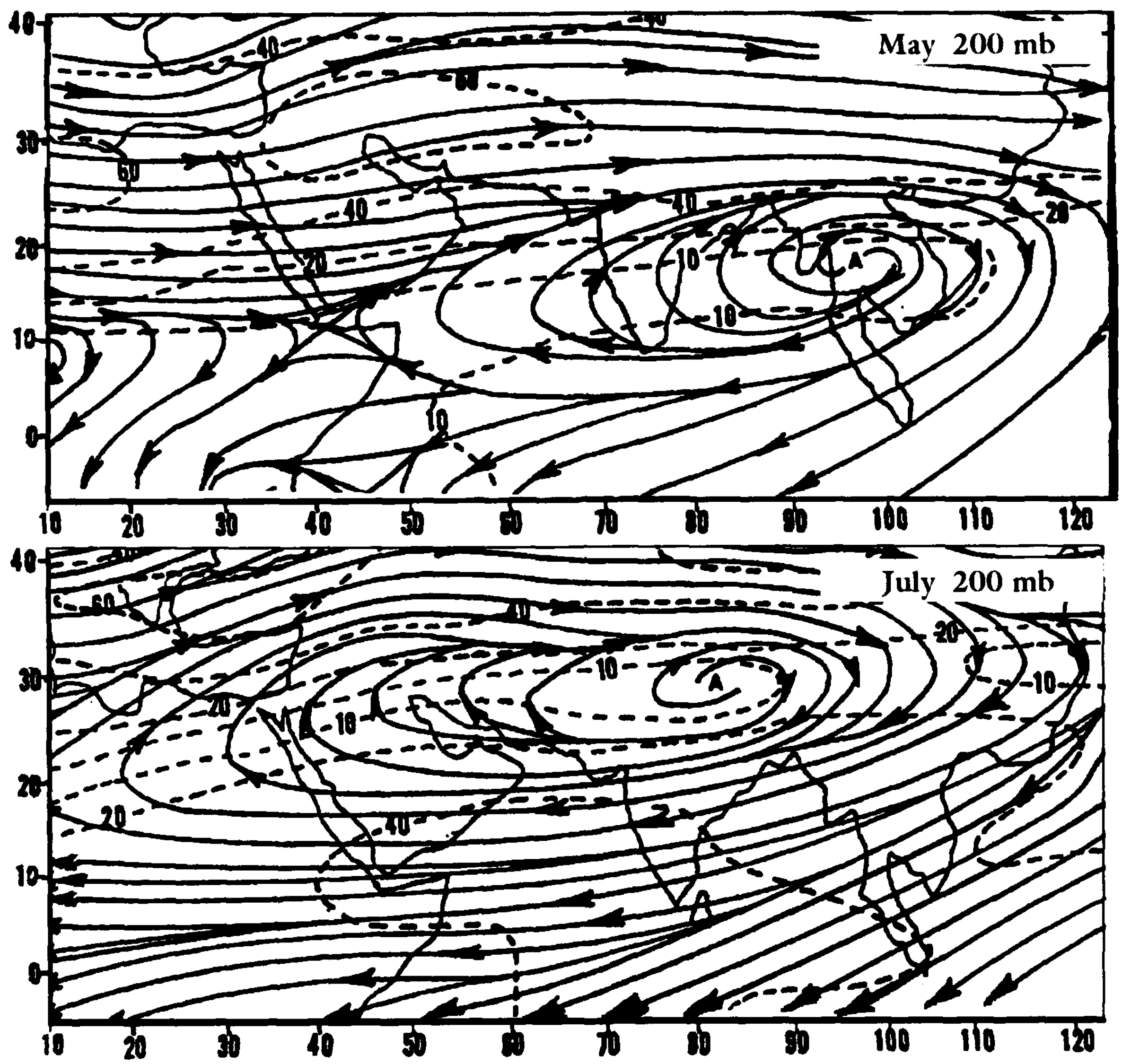


Figure 2-30. Mean May and July Positions of the Tibetan Anticyclone. The figure shows the migration of the Tibetan Anticyclone as it strengthens.

The Tibetan anticyclone intensifies the easterlies to its south and provides the upper-level divergence important for southwest monsoon rains. The northward movement of the Tibetan anticyclone is necessary for the establishment of the southwest monsoon. Figure 2-31 shows an example of this process. The numbers represent 5-day periods beginning 16 April and ending 4 July 1979. The abrupt northward jump between periods 5 and 6 (11-15 May) coincides with the onset of the southwest monsoon. The Tibetan anticyclone became established over the Tibetan plateau during period 14 (20-25 June). After period 14, the path of the anticyclone splits. A portion goes westward and a portion goes eastward. By period 16, the anticyclone has clearly broken into two cells, one in central China and the other well to the west. The number 15 (not shown) in figure 2-31 is the western cell and number 16 represents the Chinese cell.

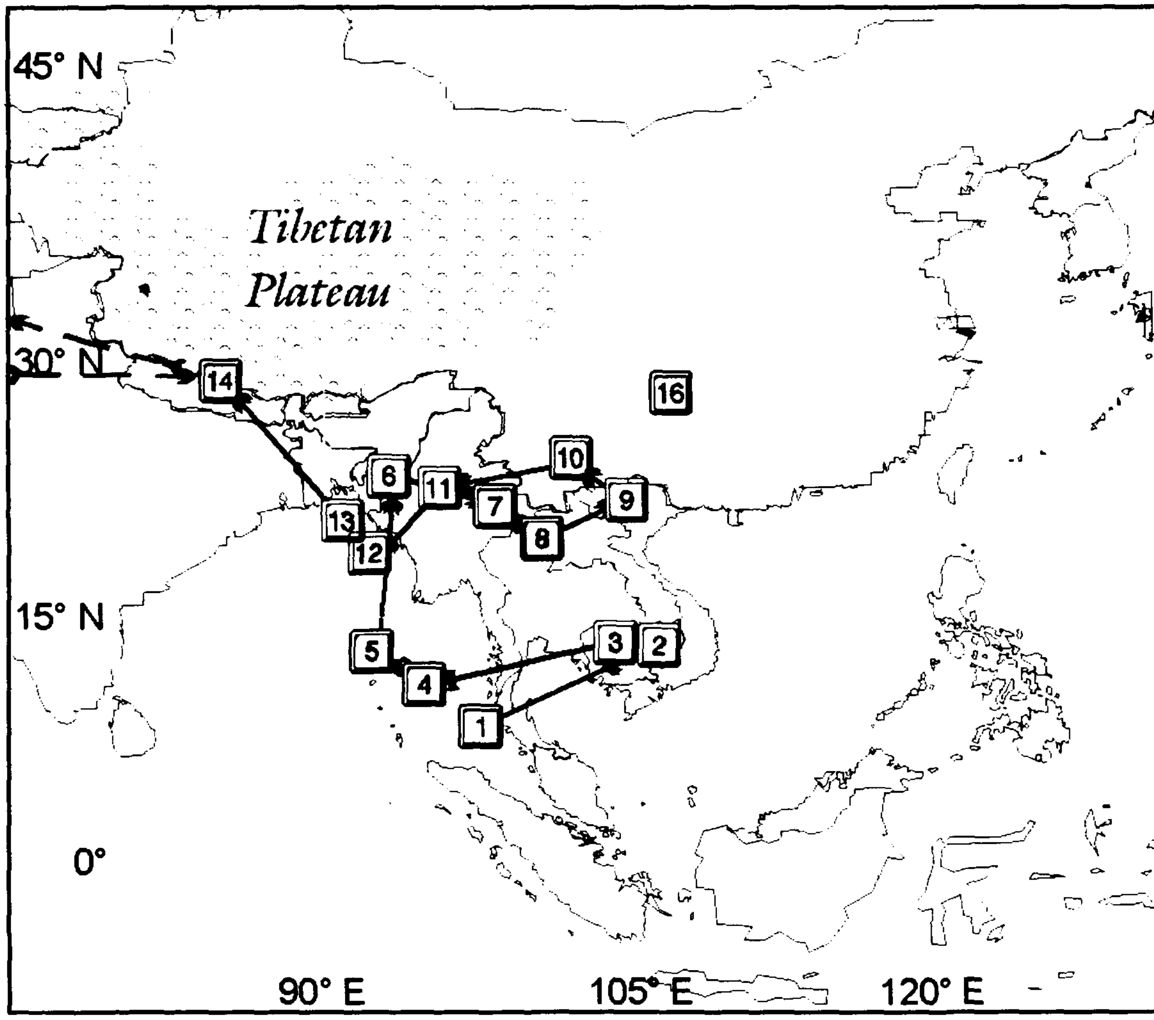


Figure 2-31. Mean Positions of the Tibetan Anticyclone at 200 mb (He, et al., 1987). See text for meaning of numbers.

Mid-Latitude Disturbances.

Cyclogenesis/Storm Tracks. The Tibetan Plateau protects southeast Asia from the direct invasion of cold air from the Asiatic high and causes a very strong baroclinic zone north of the region. Most mid-latitude disturbances miss southeast Asia entirely or pass through only northern Myanmar and Vietnam (see Figure 2-32).

Lows (known locally as "western depressions") affect northern Myanmar one to four times a month from January through April. These disturbances begin as shortwaves that move southeast from the Mediterranean through southwest Asia and India. Fronts are not normally associated with these lows. The lows become stronger when there is strong cold air advection from north-central China.

The mean position of the polar front in January is across northern Vietnam at about 25° N. As shown in Figure 2-33, fronts often stall as they cross Vietnam's Annam Mountains and the mountains of Hainan Island; they rarely penetrate into Laos.

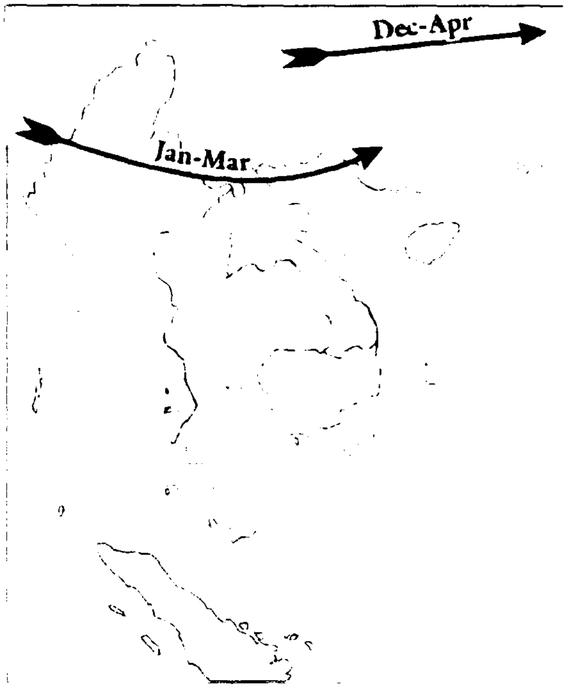


Figure 2-32. Mean Storm Tracks along the Polar Front. Storm tracks graze the northern edge of southeast Asia.

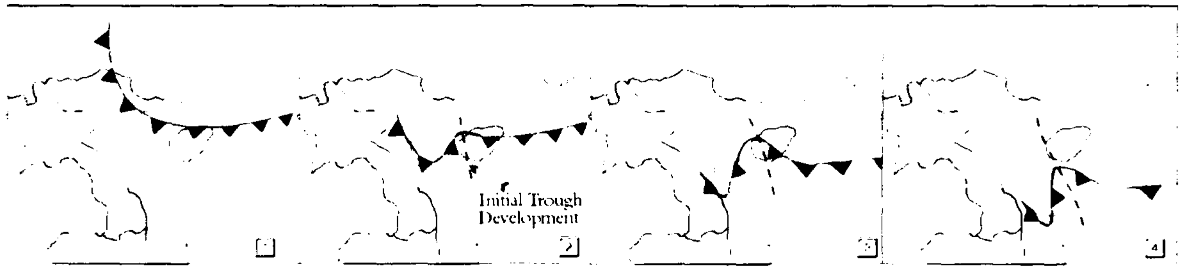


Figure 2-33. Development of a Front Passing through the Gulf of Tonkin. The resulting trough amplifies cloudy conditions over northern Vietnam.

Fronts weaken as they move away from the quasi-stationary STJ and come under the influence of the North Pacific high's subsidence layer. Cloud depths and rainfall amounts decrease, but the fronts are still marked by temperature, pressure, and wind changes. Fronts often stagnate and deteriorate into shear lines over the South China Sea.

The Asiatic high often suppresses cyclogenesis until disturbances reach the China Sea where lows develop explosively. These lows pull cold air rapidly southward and eastward. This causes a "surge" in the northeast monsoon. As the low moves northeastward, the monsoon gradually weakens until the next low comes through.

Fronts associated with surges do not normally extend south of 10 to 12° N, though their remnants have been detected at Singapore. By the time fronts reach this far south, the air masses behind them are highly modified by the trek over the South China Sea. The shallow boundaries of these fronts produce rainfall over a much larger area than frontal boundaries in temperate latitudes.

During the southwest monsoon, the storm track is well to the north. The development of a strong low-pressure system to the north can initiate eastward-moving cells in the subtropical ridge, which inhibits rainfall below. Southern Hemisphere frontal systems occasionally come close enough to generate disturbances along the NETWC, especially in September when a long-wave trough develops over Australia.

Kun-ming Quasi-Stationary Frontal Zone. The "Kun-ming" quasi-stationary front separates the cloudy, polar air of the northern Yunan Province (visible in the northwestern portion of Figure 2-34) from the drier, subtropical air to the south. This front is the northern boundary of a shear line that extends to eastern Myanmar. The shear line is visible as a convergence zone on January's 850-mb streamlines (see Figure 2-25). The Kun-ming front is most active in spring, especially when a monsoon depression forms over India or a 500-mb trough extends over the Bay of Bengal.

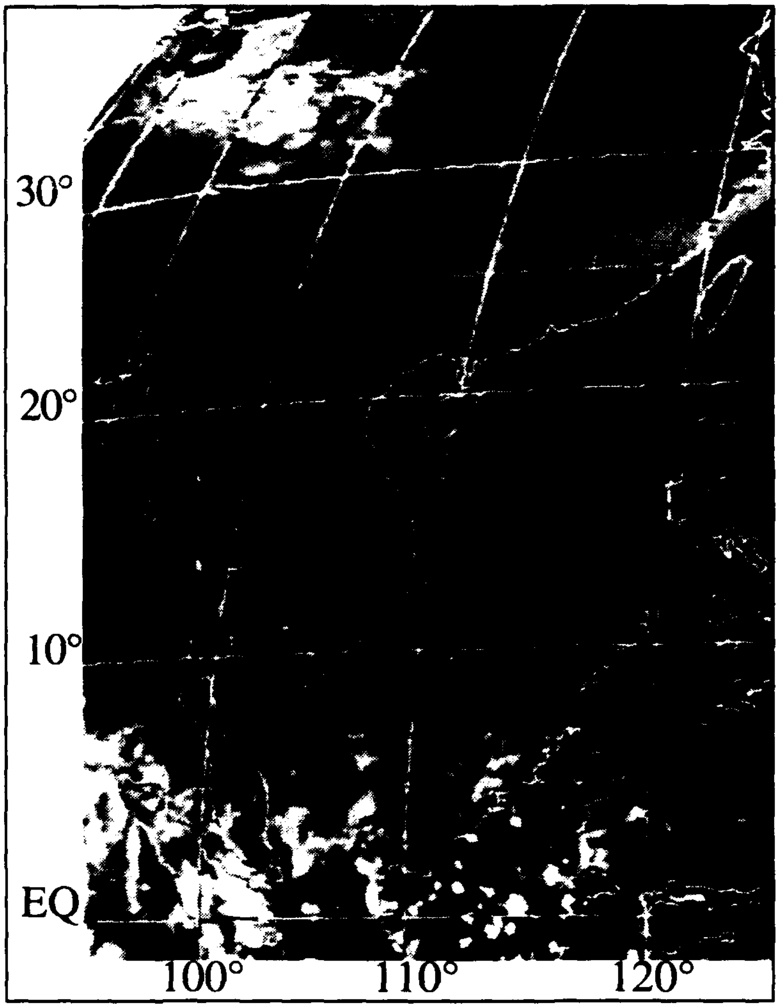


Figure 2-34. GMS IR Image 04Z, 14 January 1989 (NOAA/ NESDIS). The Kun-ming quasi-stationary frontal zone is visible in the northwest portion of this satellite image.

Cold Surges. Cold surges occur every 5 to 20 days during the northeast monsoon. They are most common in December and January, when about four a month reach the equatorial South China Sea. Figure 2-34 shows a satellite image of a typical cold surge. Note that most clouds are restricted to low levels and are blocked by the Annam Mountains of Vietnam. The cloudless skies over most of southeast Asia are typical of the northeast monsoon. Since the fronts are very shallow, usually confined to below 700 mb, it is often difficult to identify a frontal zone associated with cold surges. Forty- knot surface winds are possible as the winds are funneled through gaps in the Annam Mountains. Figure 2-35 shows typical streamlines and wind speeds during a cold surge.

Surges begin with a strengthening of the Asiatic high, possibly due to fronts passing north of the Himalayas and intensifying along the coast of eastern Asia. If cyclogenesis occurs, the surge is associated with a front and is easily identifiable; if cyclogenesis does not occur, the monsoon flow abruptly strengthens, and the leading edge of the surge is difficult to determine.

The northeast trades behind the surge are strengthened for 3-4 days after the surge's onset, enhancing convection over the western Pacific Ocean. Surges establish an east-west pressure gradient in the equatorial South China Sea, triggering eastward-moving waves in the southern NETWC.

When a cold surge reaches the southern Malay Peninsula, a quasi-stationary disturbance often develops over the South China Sea. Although these disturbances bring heavy rain to northern Borneo, they cause clearing over Malaysia, which lasts foı several days.

Some surges traverse the entire South China Sea in less than a day (corresponding to a speed of about 60 knots), producing sudden increases in cloudiness and precipitation. When these surges move over the still-warm ocean early in the northeast monsoon season, they generate considerable convective activity.

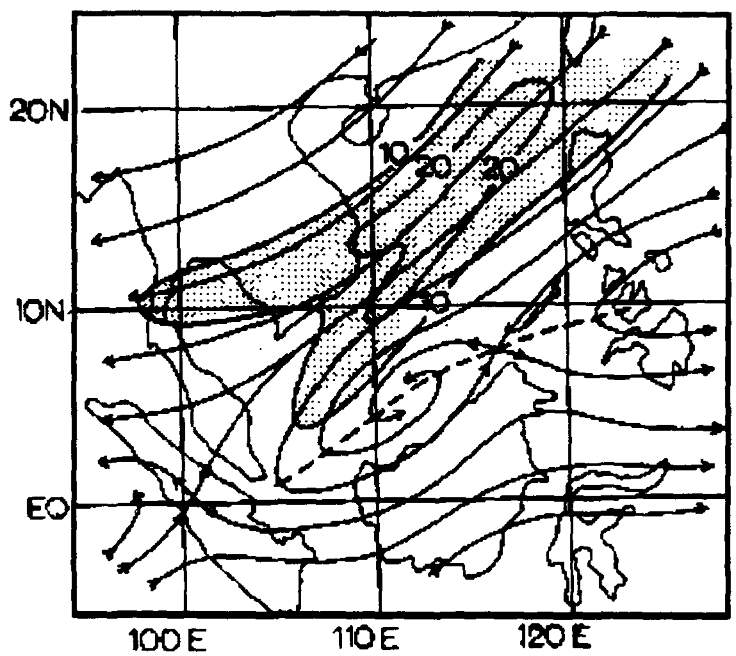


Figure 2-35. Streamlines and Isotachs (m/s) during a Typical Cold Surge (Lim and Chang, 1981). Shaded areas have wind speeds above 20 knots; the dashed line indicates the NETWC.

Yangtze Highs. These features form in southeastern China late in the northeast monsoon (after December) as the northern NETWC shifts southward. They cause the northeast monsoon winds to become more easterly, or even southeasterly, creating a "lull" in the monsoon. When an intense, mid-latitude system passes, very cold air dammed behind the Tibetan Plateau reinforces the high. An accompanying heat low often forms in northern Vietnam's Red River Valley, as does a low-level jet near 700 mb. Figure 2-36 shows the movement of an intense Yangtze high that lasted 4 days. When a Yangtze high is strong, it may cause a cold surge to travel far south, bringing heavy rainfall to Malaysia and Singapore.

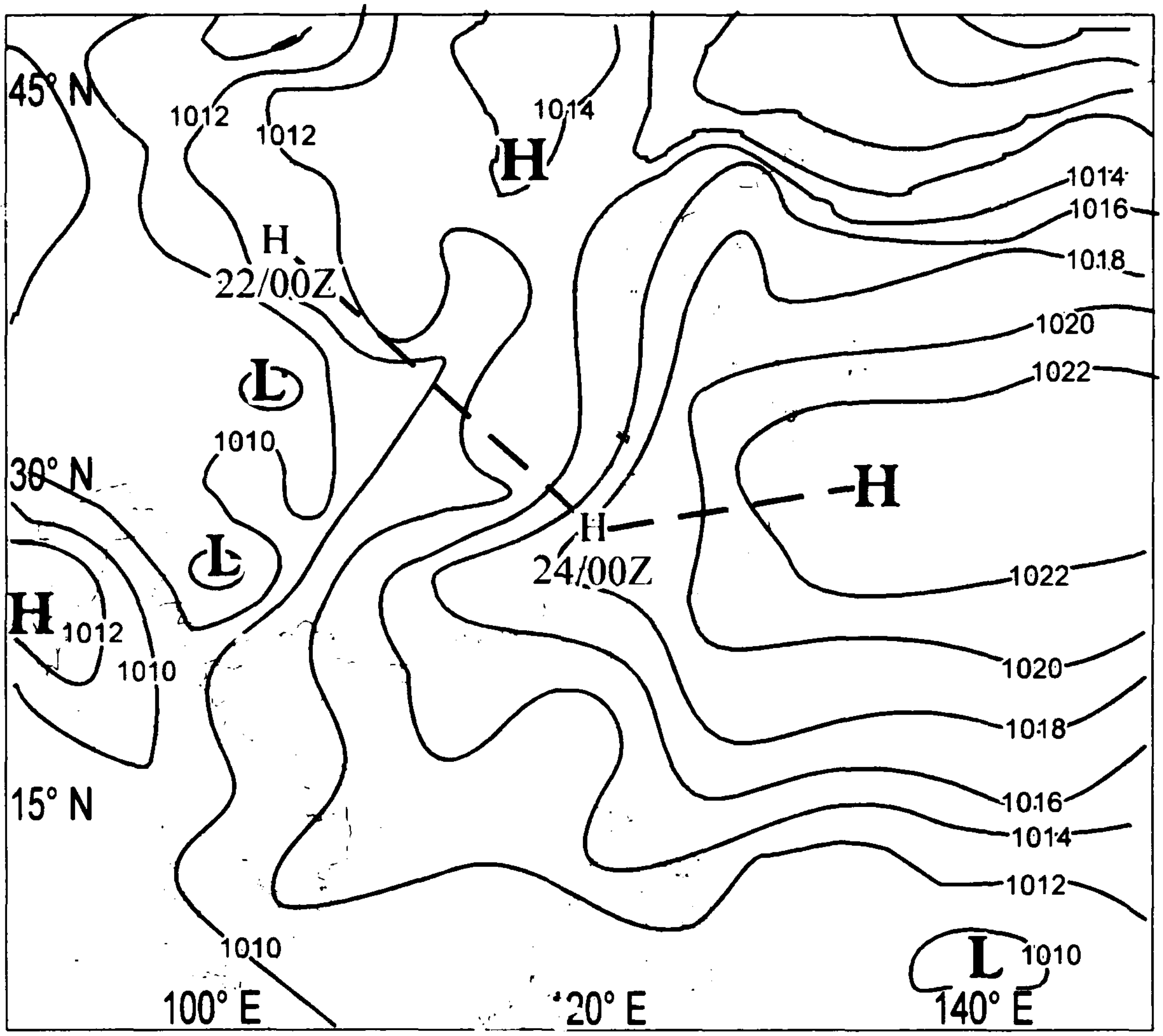


Figure 2-36. Surface Analysis 00Z, 25 March 1967, showing a Yangtze High. Previous positions of the high are also shown; movement is indicated by dashed lines.

Subtropical Disturbances.

Meiyu Front. This feature forms in southeastern China from May through June. As the northern NETWC meets drier air to the northeast, the NETWC is transformed into the "Meiyu front," a subtropical disturbance that causes widespread precipitation. Over southern China, it resembles a dry line with strong horizontal wind shear and a sharp moisture discontinuity. The associated trough is shallow and capped by a 500-mb warm core. Farther east, where it is known as the "Baiu front," it exhibits more front-like characteristics. The Meiyu front is quasi-stationary, generally located along 25° N. Its position and strength are closely tied to sea-surface temperatures in the South China Sea and the positions of the North Pacific high and the India-Myanmar trough.

The Meiyu front generally dissipates as it moves southward into Vietnam; this movement is shown in Figure 2-37. Interaction between the front and the southwest monsoon flow sometimes causes mesoscale convective complexes (MCCs) to form in northern Vietnam.

Troughs in the Subtropical Westerlies. Also called "tropical troughs," these cause much of the cloudiness over northern Vietnam late in the northeast monsoon. They originate over Africa or the eastern Mediterranean and are most easily identifiable at 300 mb. They often damp out over the Indian Ocean, then strengthen between 90 and 100° E, possibly due to lee-side effects. About four tropical troughs affect southeast Asia between January and April. Northern Vietnam normally experiences a few days of clearing ahead of the troughs, followed by stratus and drizzle. Strong troughs cause extensive, northward-moving disturbances that often develop into lows over the South China Sea. The troughs normally dissipate without moving when the normal flow reestablishes itself. If they do move, they rapidly dissipate east of 105° E.

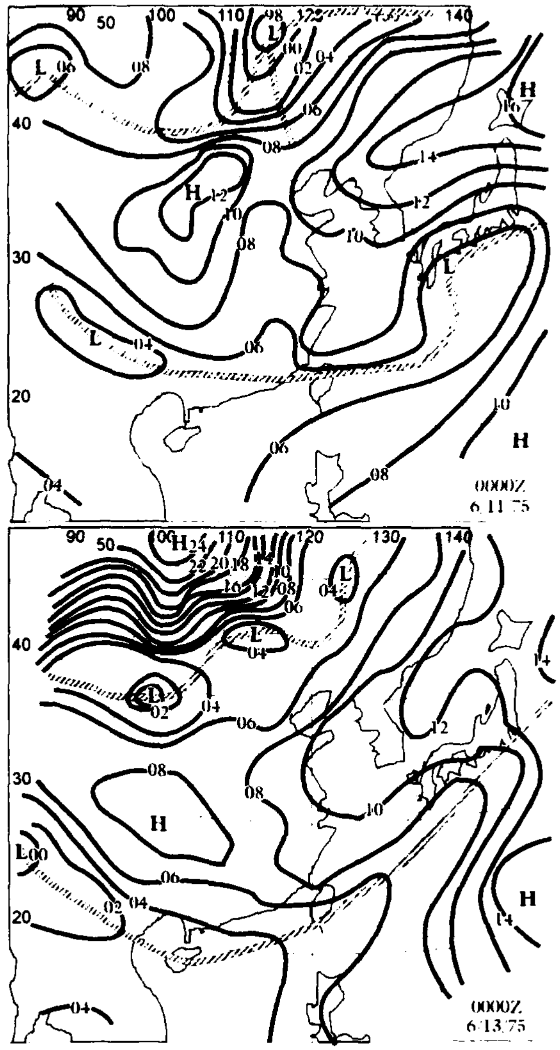


Figure 2-37. Surface Analysis 11 June (top) and 13 June (bottom) 1975. The hatched lines indicate frontal positions (Chen and Tsay, 1978).

Figure 2-38 shows a typical tropical trough at the surface. This trough developed from a weak wave that appeared west of the Red Sea on 28 February 1963. By 4 March, it was located over central India. It passed Ho Chi Minh City (Saigon) by 06Z, 8 March, then the trough became quasi-stationary and dissipated near Hanoi on 11 March.

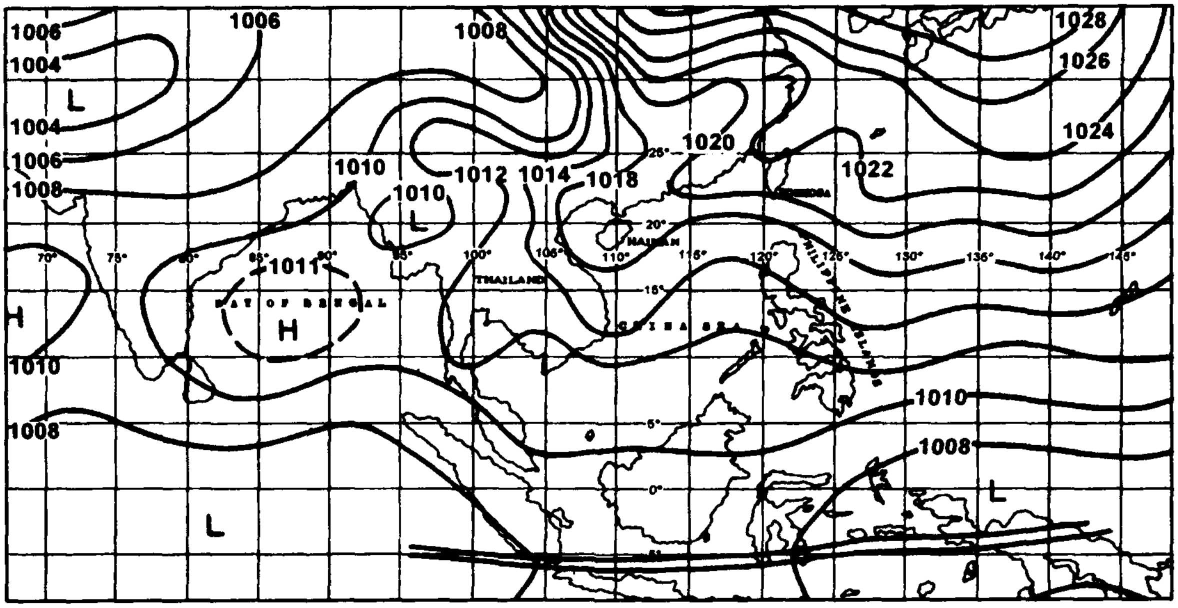


Figure 2-38. Surface Analysis 00Z, 8 March 1963. The figure shows a tropical trough in Myanmar (McCutchan and Helfman, 1969).

Subtropical Cyclones. Subtropical cyclones usually develop over the oceans surrounding southeast Asia from February to June, when a pocket of cold air is cut off south of the polar westerlies. They primarily affect the areas north of 10° to 15° N. Rapidly filling typhoons in the South China Sea can also spawn subtropical cyclones over Vietnam. During the southwest monsoon, these systems affect areas north of southeast Asia, but at other times they supply a significant portion of western Burma's rainfall. Figure 2-39 shows the synoptic pattern these cyclones follow.

Subtropical cyclones produce heavy rainfall, with the heaviest bands and the strongest surface winds found several hundred kilometers from the center. Thunderstorms occur only outside the main circulation. Latent heat release through deep convection may provide enough warming to create the appearance of a tropical cyclone and can actually change the low into one.

Also known as "monsoon mid-tropospheric lows" or "mid-tropospheric cyclones," these disturbances are most apparent between 700 and 500 mb and are often hardly detectable at the surface. Maximum wind speeds (40 knots) are found at 600 mb. They are cold-core at low levels and warm-core above. Trade winds prevail at the surface away from the center, and a subsidence inversion lies overhead. Trade wind flow is disrupted at the surface near the center. The cyclone may or may not actually develop a surface low. Figure 2-41 shows a vertical cross section of a subtropical cyclone.

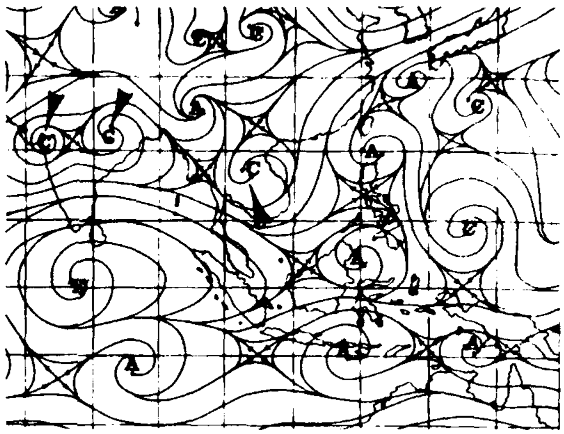


Figure 2-39. Streamlines at 500 mb 12Z, 7 July 1963 (Krishnamurti and Hawkins, 1970). Figure shows three subtropical cyclones.

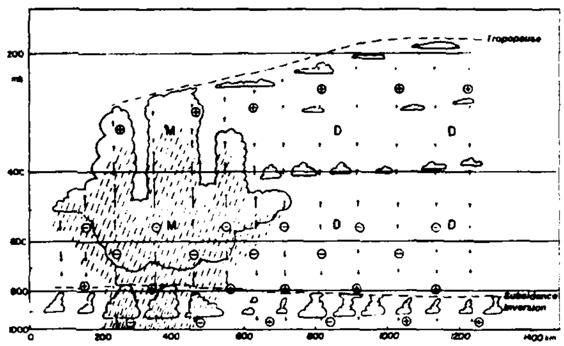


Figure 2-40. Vertical Cross Section of a Subtropical Cyclone (Ramage, 1971). Divergence is indicated by plus signs, convergence by minus signs. Regions of vertically moving air undergoing dry adiabatic temperature changes are denoted by a "D"; regions undergoing moist adiabatic temperature changes are denoted by an "M."

Tropical Disturbances.

Tropical Storms and Typhoons. These features are a major threat to southeast Asia. Nearly 80 percent of all typhoons develop in the vicinity of the NETWC over the western Pacific Ocean, east of the Philippines, though several form in the South China Sea and the Gulf of Thailand. About half of all tropical depressions (wind speeds below 34 knots) develop into tropical storms (wind speeds of 34 to 63 knots) or typhoons (winds greater than 63 knots). Most depressions that do not intensify into tropical storms or typhoons turn south instead of north. Figure 2-42 shows the average number of tropical cyclones/typhoons occurring per 250 x 250 NM square during various months in southeast Asia.

Almost 40 percent of the typhoons over the South China Sea move inland over Vietnam. About 95 percent of these typhoons hit between July and November, with a September maximum. As many as 11 typhoons have hit the Vietnamese coast in one year. The period before a typhoon strikes is one of the few times that this coast is clear. After the typhoon hits, heavy rain (up to 400 mm a day) can fall as far as 150 km from the storm center and last 2-5 days.

Even typhoons that do not hit southeast Asia can have a profound effect on its weather. When a typhoon is in the northern South China Sea, ridging to the west causes subsidence and brings dry weather to much of southeast Asia. However, if the typhoon is embedded in the NETWC, a mid-tropospheric cyclone tends to develop over southeast Asia (see Figure 2-43). Rainy weather develops in the convergence zone west of the typhoon track. An unusually active period of typhoon formation and typhoon motion north of 30° N indicates a break in the northeast monsoon.

Tropical storms that form in the South China Sea sometimes regenerate in the Bay of Bengal after crossing southeast Asia. This usually occurs when the subtropical ridge lies farther south than normal, or when a very deep, synoptic-scale cyclone surrounds the storm. Tropical storms weaken rapidly crossing the mountains and traverse Myanmar and Thailand as weak depressions.

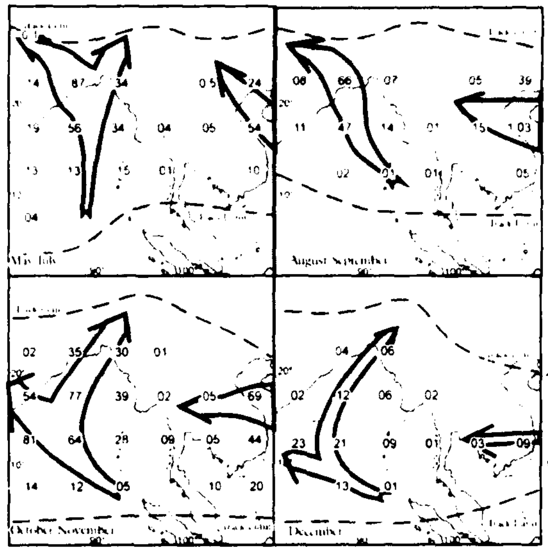


Figure 2-41. Tropical Storm Tracks and Yearly Probability of Occurrence in a 5-Degree Area during the Indicated Months. Arrow width is directly proportional to probability of occurrence.

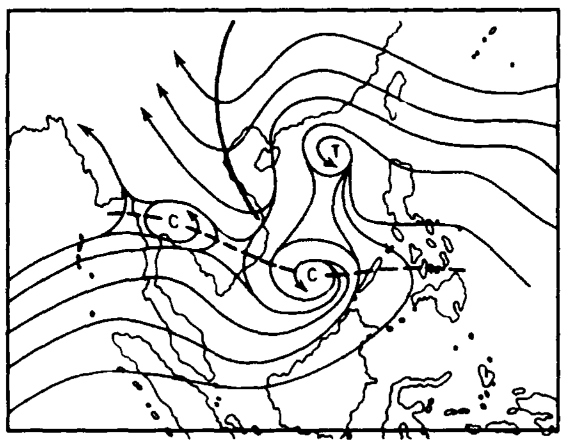


Figure 2-42. Low-level Streamlines over the South China Sea (Cheang, 1987). Solid line is ridge line. The "T" indicates a typhoon; the dashed line shows the NETWC.

Tropical Cyclone. This is the generic Indian Ocean name given to tropical storms with wind speeds above 33 knots. Tropical cyclones in the Bay of Bengal form most frequently along the NETWC during the transition seasons, particularly during the southwest to northeast monsoon transition. Tropical cyclones in the Bay of Bengal can usher in a burst in the southwest monsoon. They generally move into Bangladesh, bringing stormy weather as far north as northern Myanmar and as far east as northern Vietnam. They cause particularly severe weather along the windward slopes of the Arakan Range. Tropical cyclones do occur in the northern Bay of Bengal during the northeast monsoon, but they occur only rarely.

Monsoon Depressions. These features form in the northern Bay of Bengal during the southwest monsoon, most frequently around 20° N, 90° E. They resemble both tropical and subtropical cyclones, though pressure gradients are much lower than in tropical cyclones. Cyclonic vorticity is strongest near 500 mb. Low-level flow associated with monsoon depressions is westerly, while upper-level flow is dominated by the easterly jet stream. Their surface circulation sometimes extends more than 250,000 square km. Figure 2-18 (see page 2-21) shows an infrared image of a monsoon depression in the northern Bay of Bengal.

These depressions sometimes cause gale-force winds over the sea, but the winds lessen as they move inland. Associated cloud patterns are usually very chaotic, showing little organization. Monsoon depressions can provide heavy rain for more than a week, with the heaviest precipitation (up to 15 cm a day) in the depression's southwest quadrant. Squall-line thunderstorms sometimes form to the north; heavy rainfall is often concentrated on the Arakan coast.

Monsoon depressions usually move west-northwestward toward India, but they sometimes recurve north or northeastward, hitting the coast of Myanmar or Bangladesh. Northward or eastward movement of the depressions is usually associated with breaks in the Indian monsoon. Monsoon depressions seldom form south of 10° N; they are weak and short-lived when they do form there.

Monsoon depressions also form in the western Pacific during the northeast monsoon and move westward over the southern Malay Peninsula. These depressions move about 7 degrees of longitude a day, causing widespread heavy rain. If a monsoon depression interacts with a southward-moving cold surge, increased low-level convergence causes intense convective activity. The disturbance sometimes develops into a tropical depression, bringing widespread torrential rain. Monsoon depressions sometimes remain stationary over Malaysia for several days before moving into the Indian Ocean.

Tropical Waves. Tropical waves are periodic, westward-moving disturbances in the easterly flow. They are seldom found south of 10° N, except over Malaysia during the northeast monsoon. Tropical waves are most identifiable at low levels. Mid-level winds are lighter than surface winds. Convergence, cloud cover, and precipitation are greatest on the eastern side of the trough.

Waves seldom produce more than an increase in mid-level cloud cover before late June, due to limited moisture. Later in the season, clouds tower to progressively greater heights, and shower activity increases as the wave approaches. Altostratus and light rain commonly occur east of the wave, and cumulonimbus rises to 3 or 4 km. Tropical waves are responsible for the precipitation maximum seen late in the southwest monsoon in some areas, particularly northern Myanmar. Tropical waves are most active when they are close to the NETWC. A tropical wave model is shown in Figure 2-44.

Equatorial Anticyclones. Also called "buffer highs," equatorial anticyclones develop in the western Pacific or the South China Sea, south of 10° N. These vortices form about eight times a year, mostly from June to September, and last 4 to 9 days. They are strongest when the Australian high is very strong. After development, equatorial anticyclones tend to move northward into southern China. They are associated with "monsoon breaks" if they move over southeast Asia. They may have some steering effect on typhoons.

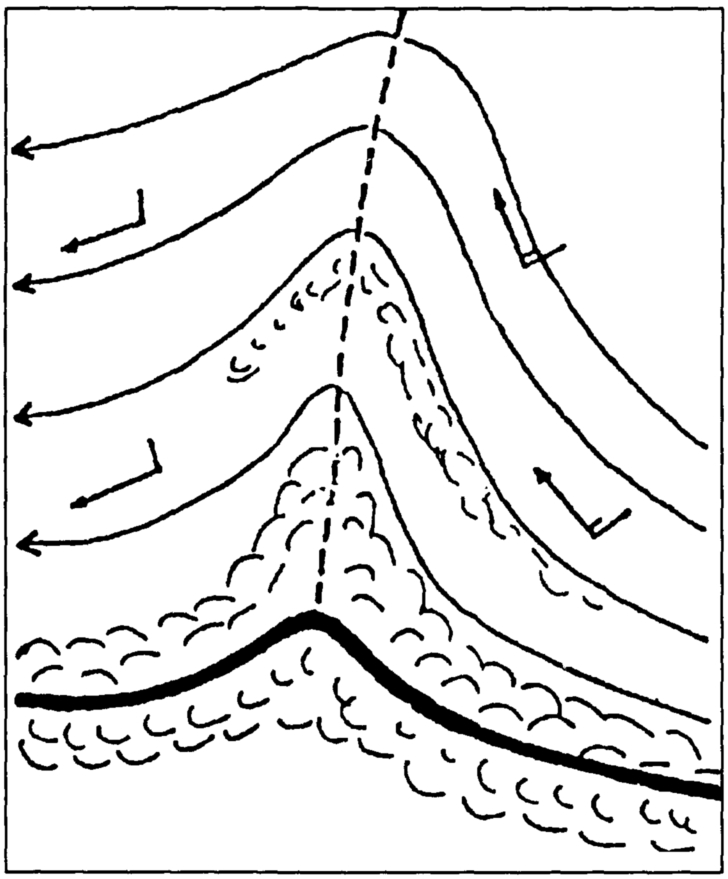


Figure 2- 3. Basic Cloud and Wind Pattern of a Tropical Wave. This classic pattern is often distorted by the NETWC and terrain.

Cloud Features.

Cloud Clusters. These features account for much of southeast Asia's rainfall during the southwest monsoon. They consist of widespread stratiform cloud decks capped by cirrus shields, with rainfall concentrated in embedded convection. These cloud clusters last 1 to 3 days and extend 300 to 1,000 km in diameter.

Mesoscale Convective Complexes (MCCs). Tropical MCCs are similar to those affecting North America's Great Plains. They form in late winter over northern Vietnam between the Meiyu front and the southwest monsoon flow. They are triggered by the interaction between thunderstorms generated by the Meiyu front or by troughs embedded in the southwest monsoon flow. MCCs produce heavy rain and hail. Figure 2-45 shows a model of a typical MCC.

The interaction between cloud clusters and sea breeze fronts can also cause MCCs to develop, as can the interaction of the NETWC with land/sea breezes over the southern Malay Peninsula during the northeast monsoon. MCCs typically last about 14 hours, moving southeasterly over land then recurving once they hit the South China Sea. They normally begin to develop in the afternoon and are most intense at night. About 40 percent of the rainfall associated with tropical MCCs is from stratiform clouds. Hail in tropical MCCs (formed by riming) is softer than that formed in MCCs farther north.

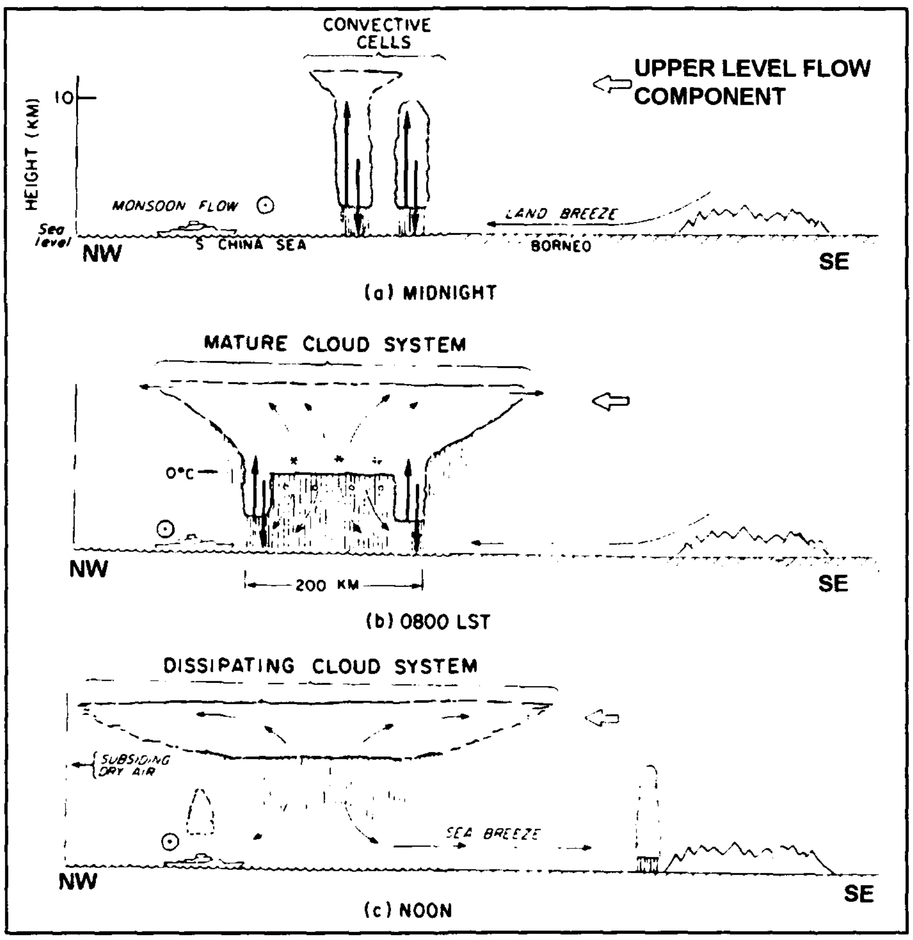


Figure 2-44. Model of the Life-cycle of a Diurnally-Generated MCC (Johnson and Houze, 1987). The figure shows the impact of land and sea breezes on the development of a MCC.

Crachin. Named from a French word meaning "to spit," Crachin is the local term for a spell of stratus, fog, drizzle, and light rain along the Vietnamese coast, normally north of 15° N. Dense sea fog is also common under these conditions. Although crachin forms along the coast, it moves inland into Laos through river valleys and over hills. Crachin is especially common in March and April. Spells normally last 3 to 5 days, though they have lasted as long as 22 days.

Fronts sometimes cause crachin, but it develops most often when easterly winds blow across the cool waters off the Vietnamese coast. These winds are associated with either a high moving offshore or a westward extension of the North Pacific high. The same conditions that cause crachin are associated elsewhere with lulls in the monsoon. Crachin associated with frontal passages is most prolonged and severe in the Tonkin area. Figure 2-45 shows a satellite photo of the Vietnamese coast during a spell of crachin associated with a frontal passage.

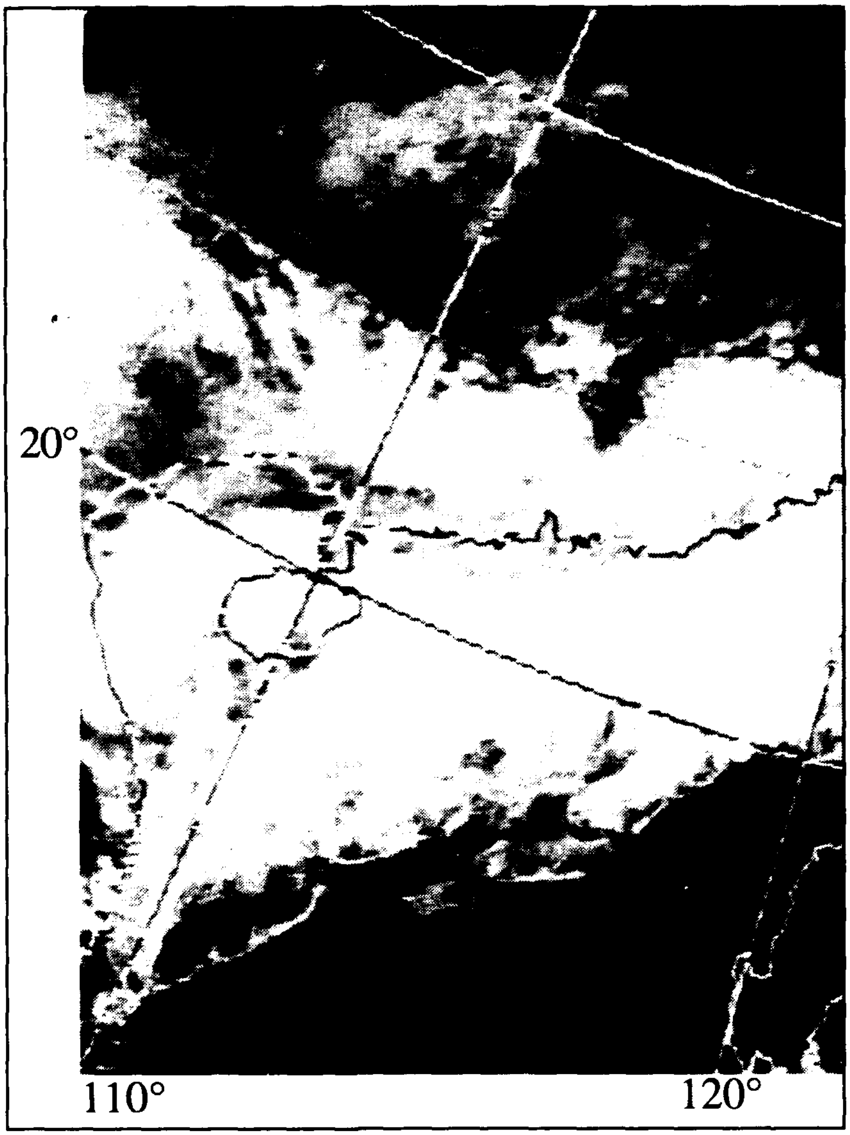


Figure 2-45. GMS Visual Image 09Z, 14 January 1989 (NOAA/NESDIS). Vietnam is located roughly left-center, on the edge of the satellite photo.

Diurnal Wind Circulations.

Land/Sea Breezes. Differential surface heating generates daytime sea breezes and nighttime land breezes along most of southeast Asia's coastline. However, coastal areas with extensive mangrove swamps, tidal marshes, or heavy irrigation usually do not have well-developed sea breezes since saturated land does not heat and cool as rapidly as dry land. With the monsoon wind reversal, land/sea breeze effects change dramatically from season to season. The breezes are most pronounced during the transition period between the northeast and southwest monsoons, when surface insolation is strongest and the synoptic-scale wind circulation is weak.

The marine boundary layer within which the land/sea breeze circulation occurs rarely extends above 900 meters AGL or beyond 30 km inland, unless modified by synoptic flow. Two types of land/sea breezes ("common" and "frontal") are described below.

"Common" land/sea breezes affect many coastal areas of southeast Asia. Figure 2-47 illustrates the common land/sea breeze circulation along a uniform coastline under calm conditions with no topographic influences. Common land/sea breezes normally reverse near dawn and dusk, with the onshore sea breeze circulation occurring during the day and the offshore land breeze at night. Common land/sea breeze circulations are especially prominent in Malaysia and Singapore, where extensive weather disturbances are rare and synoptic flow is weak. Wind shifts associated with the sea breeze circulation along the northeastern Malay Peninsula are found more than 100 km inland, though temperature/dew point changes penetrate only about 20 km. Common land/sea breezes also become well-developed along Thailand's coast, where mountains block the southwest monsoon flow.

"Frontal" land/sea breezes occur when a breeze circulation forms in combination with strong flow perpendicular to the coast. In these cases, a boundary such as that shown in Figure 2-48 forms. This is often linked to low-level jets. *Onshore* gradient flow enhances the sea breeze; *offshore* gradient flow strengthens the land breeze while weakening the sea breeze. With offshore flow, the time of the wind reversal is delayed by 1 to 4 hours as gradient flow prevents the sea breeze boundary layer, or "front," from moving ashore. Under these conditions the strongest sea breezes may occur near midnight.

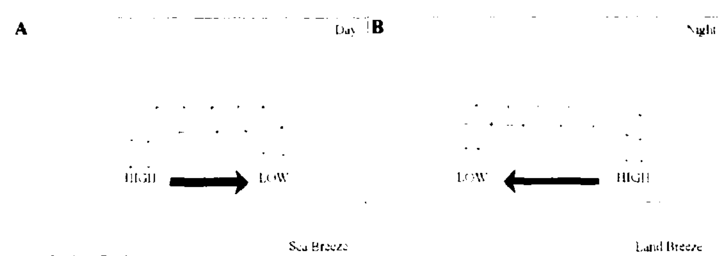


Figure 2-46. The "Common" Sea (A) and Land (B) Breezes. Thick arrows depict the surface flow. Onshore (A) and offshore (B) flow intensifies in proportion to the daily heat exchanges between land and water.

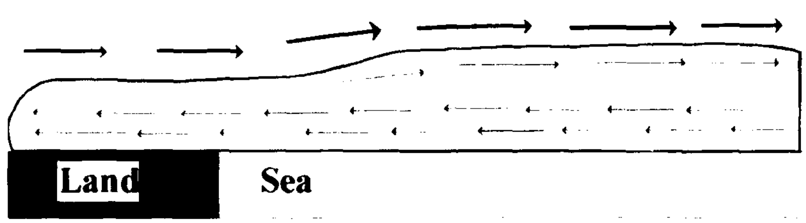


Figure 2-47. A Fully-Formed "Frontal" Sea Breeze. Light arrows depict wind flow; grey-shaded area is the marine air mass; heavy arrows depict low-level jet. Left boundary represents the sea breeze "front" onset point.

High terrain near the coastline modifies the land/sea breeze in several ways. Orographic lifting produces sea breeze-stratiform/cumuliform cloudiness over the higher terrain, while nocturnal downslope winds from the mountains accelerate the land breeze over water. Convective activity along the Vietnamese coast is enhanced in the afternoon during the southwest monsoon, due to convergence between the sea breeze and the southwest monsoon flow. Figure 2-49 shows how the land/sea breeze circulation is affected by onshore gradient winds and coastal topography. Onshore gradient flow accelerates orographic lifting by day, which enhances cloudiness over ridge tops. It also produces localized cloudiness over the open water during the early morning, due to convergence with the land breeze and downslope flow from the high terrain.

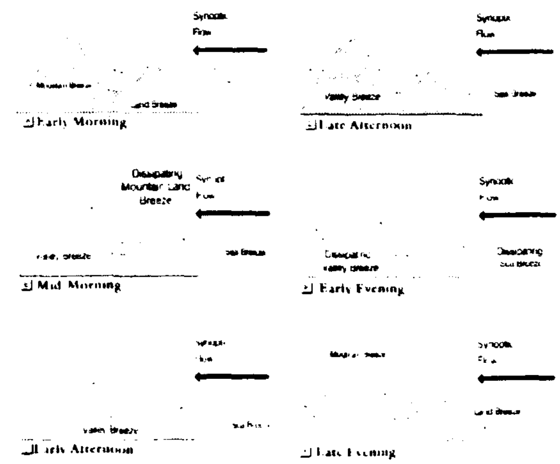


Figure 2-48. Land/Sea Breezes with Onshore Gradient Flow. Topography can lead to localized cloudiness.

Coastal configuration also has an affect on land/sea breezes. Coastlines perpendicular to landward synoptic flow maximize sea breeze penetration, while coastlines parallel to the flow minimize them. The sea breeze at Nha Trang (12° N, 109° E) diverges due to the concave coastline; this divergent flow helps dissipate the crachin that forms there.

Land/Lake Breezes. Several localized variations of a land/sea breeze circulation are caused by differential heating over large lakes. This circulation occurs in the absence of strong synoptic flow and has a vertical depth ranging from 200 to 500 meters AGL. Figure 2-50 shows an idealized land/lake circulation and the cloud patterns associated with it. In the late afternoon (top illustration), a cloud-free lake is surrounded by a ring of convection, some 20 to 40 km in diameter. By early morning, the flow reverses and localized convergence occurs over open water.

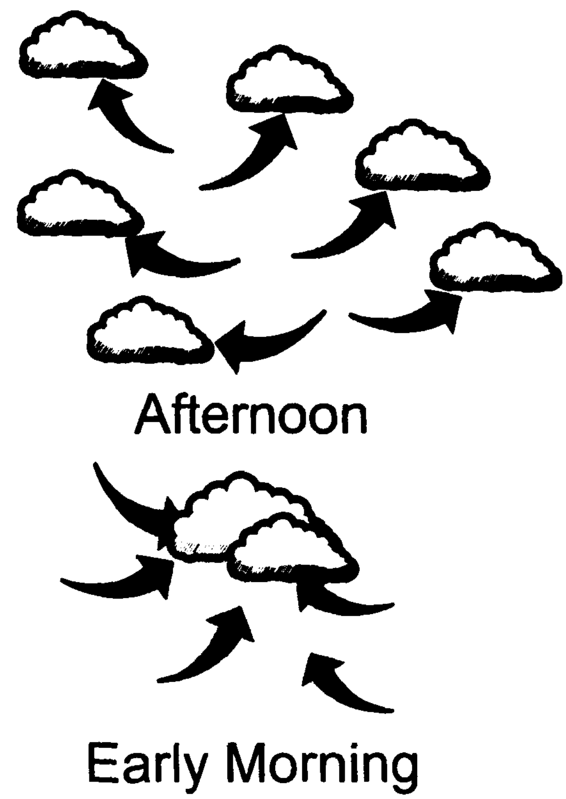


Figure 2-49. Idealized Land/Lake Breezes with Cloud Pattern. Changes in localized convergence leads to changing cloud patterns.

Mountain-Valley and Slope Winds. These localized winds develop under fair skies with light and variable synoptic flow. Mountain-valley winds, like land/sea breezes, dominate the weather close to the equator, especially when the monsoon is weak. A strong monsoon diminishes these effects, particularly away from the equator. Nocturnal mountain winds that flow toward the sea cause lines of thunderstorms, especially in Malaysia and peninsular Thailand. The two types of terrain-induced winds, valley winds and slope winds, are shown in Figure 2-51 and discussed below. Valley winds tend to be stronger than slope winds and can override their influence.

Valley winds are produced in response to the pressure gradient that develops between a mountain valley and an outlying plain, since air within the valley heats and cools faster than air over the plain. Daytime, up-valley winds are strongest, averaging 10-15 knots between 200 and 400 meters AGL. Nighttime, down-valley winds average only 3-7 knots at the same level. Peak winds occur at the valley exit. Because nocturnal airflow convergence is stronger in deep valleys, more nocturnal cloud cover develops than in shallow valleys. The mountain-valley circulation normally has a maximum vertical extent of 2,000 meters AGL. Its limit, however, is determined by the valley's depth and width, the strength of prevailing winds in the mid-troposphere (stronger winds producing a shallower circulation), and the breadth of microscale slope winds. The return flow aloft is much weaker and broader since it is not confined to a narrow valley.

Slope winds develop along the surface boundary layer of mountains and large hills and seldom extend beyond 150 meters AGL. Mean daytime upslope wind speeds are 6-8 knots; mean nighttime downslope wind speeds are 4-6 knots. Steep slopes can produce higher speeds, but these speeds are confined to heights below 40 meters AGL. Downslope winds are strongest during the season of greatest *cooling*, while upslope winds are strongest during the season of greatest *heating*. Upslope winds are strongest on the slope facing the sun, and winds from a large mountain can disrupt those of a smaller mountain. In some locations, cold air can be dammed up on a plateau or in a narrow valley. When sufficient air accumulates, it can spill over in an "air avalanche" of strong winds.

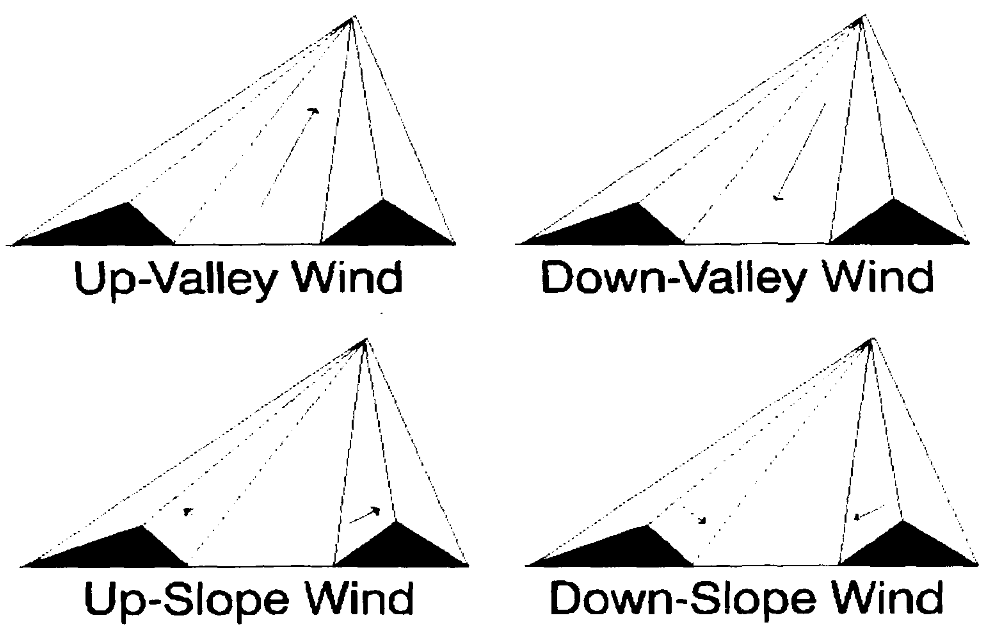


Figure 2-50. Mountain-Valley and Slope Winds (Whiteman, 1990). These terrain-induced features are triggered by diurnal temperature changes. The arrows indicate direction of wind flow.

Figure 2-52 shows the life cycle of a typical mountain-valley and slope wind circulation. Mountain inversions develop when cold air builds up along wide valley floors. Cold air descends slopes above the valley at 8-12 knots but loses momentum when it spreads out over the valley floor. Wind speeds average only 2-4 knots by the time the downslope flows from both slopes converge. The cold air replaces warm, moist, valley air at the surface and produces a thin smoke and fog layer near the base of the inversion. First light initiates upslope winds by warming the cold air trapped on the valley floor. Warming of the entire boundary layer begins near the 150-meter AGL level.

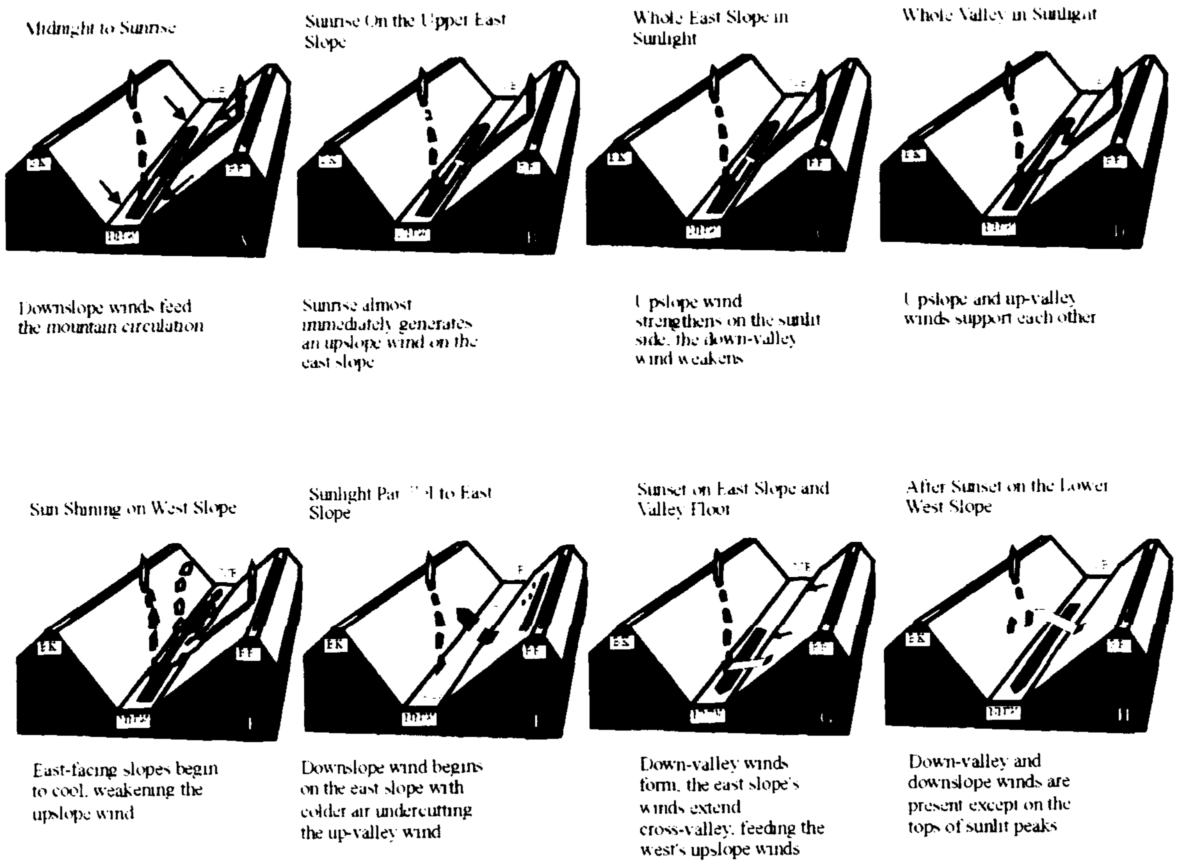


Figure 2-51. Diurnal Variation of Slope and Valley Winds (Barry, 1991). Both valley and slope winds are shown in relation to two ridges (BK and BB) oriented NNW-SSE. Dark arrows show flow near the ground; light arrows show flow above the ground.

Convergence Lines (Sumatras). The development of convergence lines between the synoptic flow and diurnal circulations is common in southeast Asia, creating thunderstorms and afternoon squall lines almost daily in some locations. In southern South Vietnam, these squall lines are sometimes accompanied by rope-like tornadoes moving northeastward in the southwest monsoon flow. Nocturnal thunderstorms are well-known in the Mekong River valley and in the northern Gulf of Thailand during the northeast monsoon.

Sumatras are nocturnal squall lines that form in the Strait of Malacca during the southwest monsoon. They develop most frequently between 2100 and 0400L off the southwestern coast of the Malay Peninsula, between Port Swettenham (3° N, 101° S) and Singapore. Sumatras are caused by the convergence of eastward moving land breezes from the island of Sumatra with westward moving land breezes from the Malay Peninsula. The southwest monsoon enhances this convergence by reinforcing the land breeze from Sumatra and moving the thunderstorms as far as 50 km inland over the Malay Peninsula. The lines of thunderstorms arrive on the Malayan coast late at night or early in the morning as a band of cumulus and cumulonimbus 200 to 300 km long. Sumatras are oriented northwest-southeast and move northeastward, sometimes as fast as 40-50 knots. They can cause heavy rainfall for 1-2 hours and winds of up to 40 knots. Rainfall can exceed 80 mm in one night. Sumatras cause a sudden temperature drop that lasts for several hours; temperatures usually fall about 3°C, but drops of 15°C in 5 minutes have been reported. Sumatras are most common in July, when 6 to 8 normally occur.

Local Wind Systems.

Mountain Waves. These features develop when air at lower levels is forced over the windward side of a ridge. Criteria for mountain wave formation include sustained winds of 15-25 knots, winds increasing with height, and flow oriented within 30 degrees of perpendicular to the ridge. The wavelength and amplitude of mountain waves are dependent on the wind speed and the lapse rate above the ridge. Light winds follow the contour of the ridge, with little wave formation. Stronger winds displace air above the stable inversion layer, forming waves. This upward displacement of air can reach the tropopause. Downstream, the wave propagates an average distance of 50 times the ridge height. Rotor clouds form when there is a core of strong winds moving over the ridge, but the elevation of the core does not exceed 1.5 times the ridge height. Rotor clouds produce the strongest turbulence. Figure 2-53 shows a fully developed lee wave system. Waves frequently develop over the mountains of northern Myanmar during strong westerly depressions, causing moderate to severe turbulence.

Foehns. These hot, dry winds occur as air that has been forced over mountain tops descends the leeward slopes adiabatically. The "Winds of Laos" are strong foehn winds that blow across Vietnam during the southwest monsoon, or (less frequently) during the transition seasons. They usually occur along the coast between Nha Trang (12° N) and Ha Tinh (18° N). They descend the slopes of the Annam Range and are often dry enough to desiccate plants. Foehns also occur along the coast of Thailand during the northeast monsoon, as well as off the Cardamon Mountains in southwestern Cambodia.

Gulf of Tonkin Eddy. This is a small-scale circulation that typically develops after a surge in the northeast monsoon. A narrow band of southeasterlies from the South China Sea is deflected around Hainan Island, forming cyclonic eddies or shear lines in the Gulf of Tonkin. These eddies are 100-200 km wide and usually move to the north. On the eastern side of the eddy, surface winds sometimes reach 30 knots, ceilings lift, and skies become less overcast.

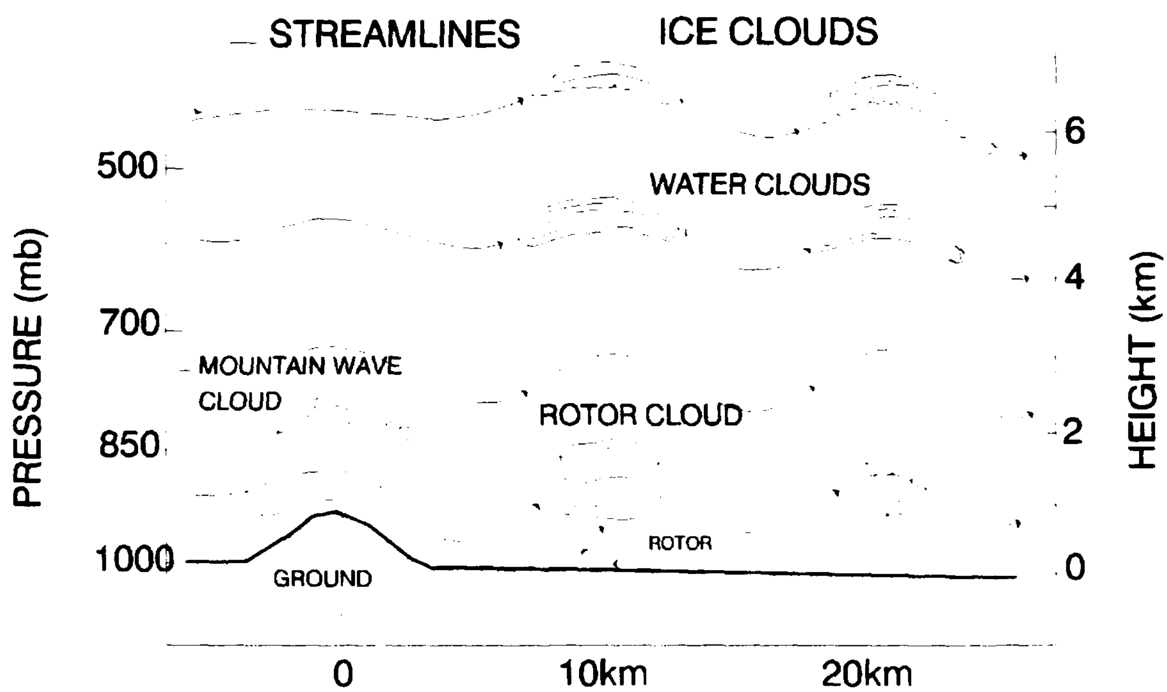


Figure 2-52. Fully-Developed Lee Wave System (Wallace and Hobbs, 1977). The arrows depict wind flow across the windward side of the mountain, resulting in mountain wave formation.

Wet-Bulb Globe Temperature (WBGT) Heat Stress Index. The WBGT heat stress index provides values that can be used to quantify the effects of heat stress on individuals. The WBGT is computed using the following formula:

$$WBGT = 0.7WB + 0.2BG + 0.1DB$$

WB = wet-bulb temperature
BG = Vernon black-globe temperature
DB = dry-bulb temperature

A complete description of the WBGT heat stress index and the apparatus used to derive it is given in Appendix A of TB MED 507, *Prevention, Treatment and Control of Heat Injury*, July 1980, published by the Army, Navy, and Air Force. The physical activity guidelines shown in Figure 2-54 are based on those used by the three services.

WBGT (° C)	Water Requirement	Work/rest Interval	Activity Restrictions
32-up	2 quarts/hour	20/40	Suspend all strenuous exercise.
31-32	1.5-2 quarts/hour	30/30	No heavy exercise for troops with less than 12 weeks hot weather training.
29-31	1-1.5 quarts/hour	45/15	No heavy exercise for unacclimated troops, no classes in sun, continuous moderate training 3rd week.
28-29	.5-1 quart/hour	50/10	Use discretion in planning heavy exercize for unacclimated personnel.
24-28	.5 quart/hour	50/10	Caution: Extremely intense exertion may cause heat injury.

Figure 2-53. WBGT Heat Stress Index Activity Guidelines. The physical activity restrictions are guidelines. Note: the wear of body armor or NBC gear adds 6°C to the WBGT, and activity should be adjusted accordingly.

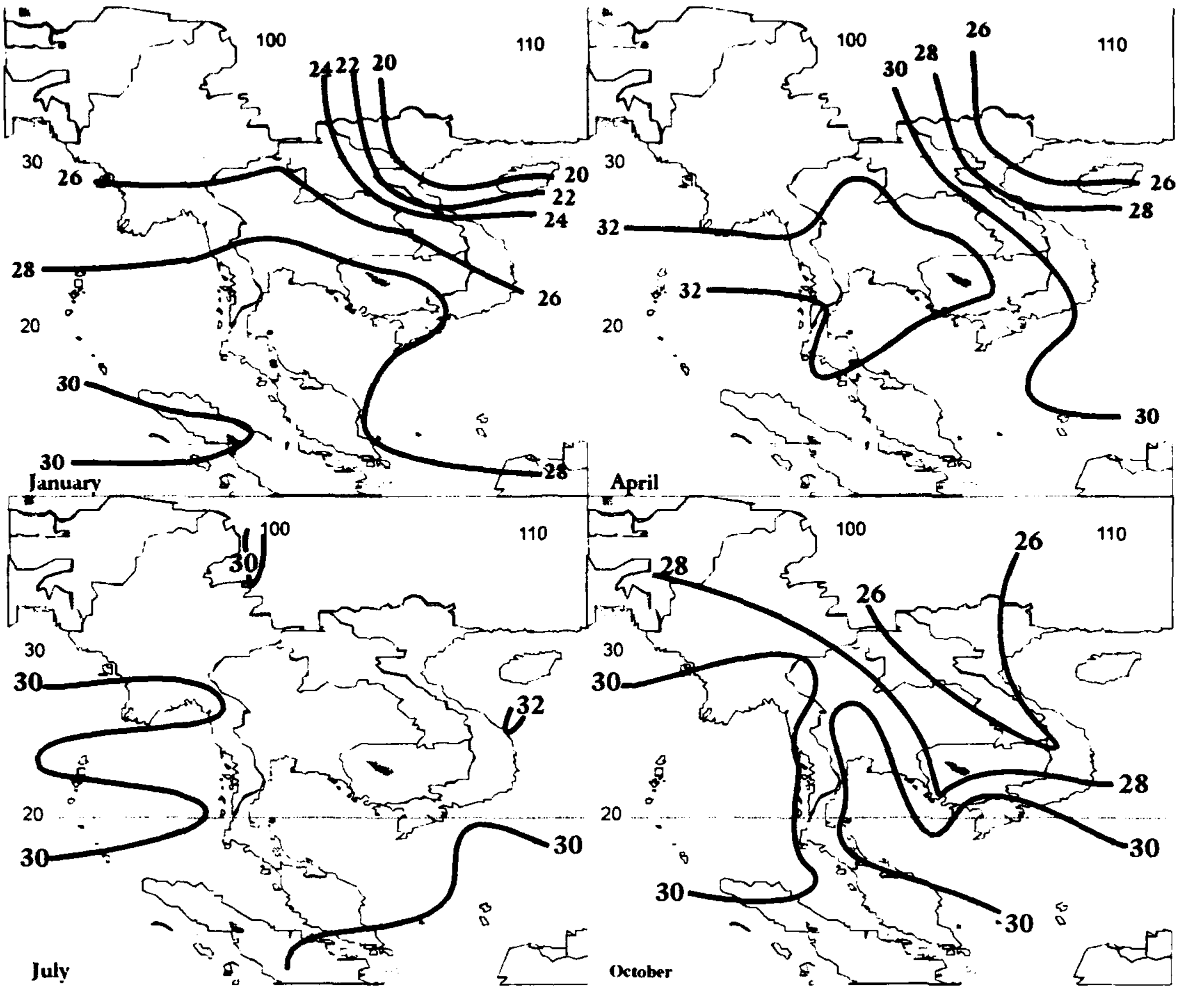


Figure 2-54. Mean Maximum WBGT, January, April, July and October. WBGTs are highest during the transition between the northeast and southwest monsoons.

Chapter 3

Northern Myanmar (Northern Burma)

This chapter describes the topography, major climate controls, special climatic features, and general weather (by season) for the northern part of Myanmar, formerly known as Burma. Although Burma is no longer the official name of Myanmar, it is widely recognized and older studies use that name. Few studies written on the meteorology and climate of the country after 1960 are available in the United States. Most usable studies come from either the India Meteorological Department or from the World War II station forecast studies prepared by meteorological units supporting USAAF operations. A fair amount of surface and some limited upper-air meteorological data continue to flow through the World Meteorological Organization's global telecommunications circuits.

Northern Myanmar

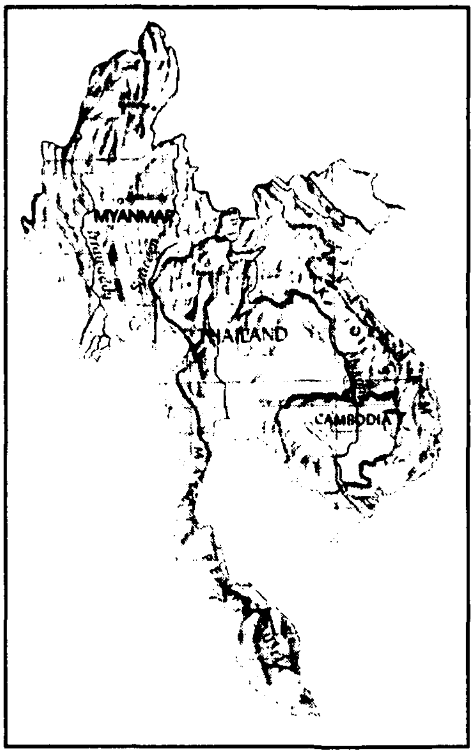


Figure 3-1. Topography. This map shows major place names, rivers, and terrain features.

Boundaries. This region contains the northern three quarters of the Irrawaddy and Sittang river valleys and all of Myanmar north of 23° N. A southward projecting "tongue" comprises the central half of the Irrawaddy River valley and the northern three quarters of the Sittang River valley. This "tongue" is bounded by the Arakan Yoma Mountains and the Chin Hills on the west and the Shan Plateau on the east. It extends north-south 225 miles in the center of Myanmar.

Topography. Terrain is uneven; the relatively low Pegu Mountains divide the Irrawaddy and Sittang River valleys. North of 23° N, the region widens to include all of Myanmar to the borders of India on the west and China on the north and east. Bounded by the mountains of Assam on the west, the eastern extensions of the Himalayas on the north, and the mountains of southwestern China on the east, it has only one major river valley. Terrain is extremely rugged. Numerous deep canyons and gorges, oriented mostly north-south, divide the ranges. The highest known mountains are along the Myanmar-China border, with heights varying from 13,000 feet (4,000 meters) to a maximum known elevation of 19,294 feet (5,881 meters) near 26° N. Higher peaks may exist as much of this area has not been adequately charted.

Rivers and Drainage Systems. The Irrawaddy River system rises in extreme northern Myanmar in the Putao Knot (northernmost tip of Myanmar) and drains southward along the east side of this area. The Chindwin River begins north of the Hukawng Valley and drains down the western side of the long valley. These are the only two major rivers in the region; however, there are many small tributary streams that drain the mountain slopes.

Vegetation. Most of Myanmar is either farmed or heavily forested. Tcak forests blanket the mountain and rice paddies and vegetable farms occupy the lowlands. Farmers in Myanmar raise a wide variety of crops.

Asiatic High. Also known as the Siberian high, this shallow, semipermanent high is caused by strong radiative cooling of the Asian continent. It sets up in September and breaks down in April. The cold, dry outflow is the primary resource for the northeast monsoon flow over all of Myanmar.

Asiatic Low. Also known as the Siberian low, this is a shallow, semipermanent low caused by strong radiative heating of the Asian continent. It sets up by the end of April and breaks down by the middle of September. The strong inflow associated with this low is partly responsible for the northward movement of the southwest monsoon.

India-Myanmar Trough. Previously known as the India-Burma trough, this quasi-stationary trough forms in the vicinity of 85° E during the southwest monsoon season. Strengthened by the tropical easterly jet, it is a preferred area for development of tropical disturbances.

Near Equatorial Tradewind Convergence (NETWC). The NETWC divides the dry, continental air to the north from the moist, maritime tropical air. The changing positions of the northern NETWC determines the wet season (southwest monsoon) and the dry season (northeast monsoon).

South Indian Ocean (Mascarene) High. Outflow from this massive high-pressure system meets outflow from the Siberian high to form the NETWC. The Mascarene high is the primary source of moisture for the southwest monsoon.

El Niño/Southern Oscillation. This phenomenon does not appear to impact northern Myanmar weather nearly as much as it does the coasts and west-facing areas in the south. It causes short-term drought conditions in those areas during the southwest monsoon, but there is no documented pattern of significant drought anywhere in Myanmar.

Thailand Heat Lows. These lows form over Thailand and Myanmar from May to July due to increasing solar insolation. As the southwest monsoon progresses north, these lows are displaced north to blend into the Siberian (Asiatic) low.

Tropical Disturbances. These weak cyclones do not directly impact northern Myanmar, but they do advect in heavy rains. Although rare in any season, they occur most often in the southwest monsoon season.

General. The whole area is under the influence of the northeast-southwest monsoon cycle. During the northeast monsoon, conditions are drier. The Asiatic (Siberian) high has pushed the monsoon front well south, and only transitory frontal systems and moisture advected onshore around stable highs bring rain to Myanmar. During the southwest monsoon, the monsoon front pushes well into northern Myanmar. Massive amounts of rain falls in most parts of the country, averaging more than 160 inches (4.06 meters) in much of the mountainous northern region. There are brief transition seasons between monsoons. The designated seasons used are those of the Indian Meteorological Department. These consist of the following two primary and two transition seasons:

Northeast Monsoon—November-March.
Pre-Monsoon—April-May.
Southwest Monsoon—June-August.
Post-Monsoon— September-October.

General Mountain Hazards. Northern Myanmar is part of and encircled by the southern slopes of the Himalaya Massif. The Hiamalyas present dangers unique to mountain ranges. High ground is cloud-shrouded most of the time, and these elevations are the highest in the world. Storms blow up unexpectedly in this high terrain and can quickly become life-threatening blizzards in any season. Travel through the mountains requires special survival precautions. Turbulence, icing, wind shear, and unbelievably rugged terrain makes travel dangerous. Pilots should keep close watch on the instruments while flying in this area. Remember! Those clouds have rocks in them!

Special Note. Because the climate of central Myanmar (the "tongue" of the area described earlier) has notable differences from the north, it will be discussed separately where applicable. The area is bounded on the far south by the confluence of the Irrawaddy and Chindwin rivers and the far north by Taguang. It is bounded east and west by the Shan Plateau and the Arakan Mountains. The difference exists because of terrain. The central part of Myanmar is in the rain shadow of the mountains surrounding it; consequently, it is drier than the rest of the country. It averages 20 to 40 inches (508 to 1,016 mm) of rain annually. Northern Myanmar, on the other hand, has terrain that induces both orographic lifting and orographic "squeezing" or funneling. The air is forced northward into progressively higher and narrower areas. This creates tremendous amounts of precipitation (in many areas, more than 160 inches (4.06 meters) annually), especially at higher elevations, despite the long distance from water.

General Weather.

Central Myanmar. In this, the dry season, the Asiatic high is centered over Siberia. Recurring cold outbreaks spread south and eastward across China and the South China Sea. The flow eventually curves around the base of the high to become northeasterly flow across central Myanmar. Because of its long trajectory, much of it over water, little is left of its original cold air characteristics. Partially blocked by the Shan Plateau and then deflected from northeasterly to northerly by the Chin Hills-Arakan Mountains, this air mass reaches the valley floor of central Myanmar relatively cool and dry. A marked diurnal mountain-valley breeze exists throughout this region extending upward to near the 3,000-foot (915-meter) contour of the mountains. Above this level, the northeast monsoon winds flow uninterrupted.

Northern Myanmar. The Asiatic high is centered over Siberia and spreads recurring cold outbreaks south and eastward across China and the South China sea. Recurring as northeasterlies, this air flows over central Myanmar and eventually, over parts of northern Myanmar. Although no longer continental polar, it still brings in drier and colder air than that of the southwest monsoon. Another type of weather system that impacts northern Myanmar weather is a low-pressure system that originates in the Atlantic Ocean. Some of these lows track across the Mediterranean and are caught up by a jet branch south of the Himalaya Massif. The jet acts as a channel to steer the low-pressure systems through India, Pakistan, and northern Myanmar. These systems bring unseasonably heavy rains as they pass through. The most common time for this type of system is December through April. Troughs in the upper westerlies, above 10,000 feet (3,100 meters), affect this region throughout the northeast monsoon. A marked diurnal mountain-valley breeze exists throughout this region extending upward to near the 5,000-foot (1,525-meter) contour of the mountains. Northeasterly monsoon winds flow between 5,000 and 10,000 feet (1,525 and 3,100 meters). Westerlies dominate above 10,000 feet (3,100 meters). Above 20,000 feet (6,100 meters), westerlies increase steadily to near 150 knots at 26,000 feet (10.7 km) reflecting the core of the subtropical jet stream.

Sky Cover. Figure 3-2 shows frequency of ceilings below 3,000 feet.

Central Myanmar. The only clouds in the upper-level flow are middle cloud and cirriform decks associated with the southern end of a strong trough in the westerlies. Bases on these layers average 8,000 to 10,000 feet MSL (2,440 to 3,100 meters); layers extend up to 30,000 to 35,000 feet (9.2 to 10.7 km). Low clouds form by late evening and dissipate by midmorning. Scattered to broken stratus and stratocumulus clouds, with bases 2,000 feet (610 meters) MSL and tops between 2,500 and 3,000 feet (760 to 915 meters) MSL, form by late evening. Mountains between 800 and 2,500 feet (245 to 760 meters) are obscured. Lower-level clouds often clear by noon. Average cloud cover is scattered with any broken conditions clearing well before noon. As the season progresses, cloud cover decreases.

Northern Myanmar. Extensive middle cloud and cirriform decks are associated with troughs in the westerlies. Bases on these layers average 8,000 to 10,000 feet MSL (2,440 to 3,100 meters); layers extend up to 35,000 feet (10.7 km). Broken low clouds shroud ridges and canyons between 2,000 and 5,000 feet (610 and 1,525 meters). This cloud cover decreases to scattered coverage during the afternoon in locations where the canyons are wide enough to permit substantial heating. Mountains between 2,000 and 5,000 feet (610 and 1,525 meters) are normally obscured except during early evenings when downslope winds may be sufficient to temporarily clear the low cloud decks. When low-pressure systems track across India and Pakistan to sweep into northern Myanmar, thick nimbostratus forms and obscures even the valley locations in the mountainous re[illegible] days. Location is an important facto[illegible] amount of cloudiness experienced. Maximum cloudiness occurs in the northeastern part of the country, where high elevations and abundant moisture combine to produce extensive cloudiness even in the dry season. For example, Putao, which is located high in the northern mountains, sees overcast low-cloud conditions an impressive 85 percent of the time, year-round.

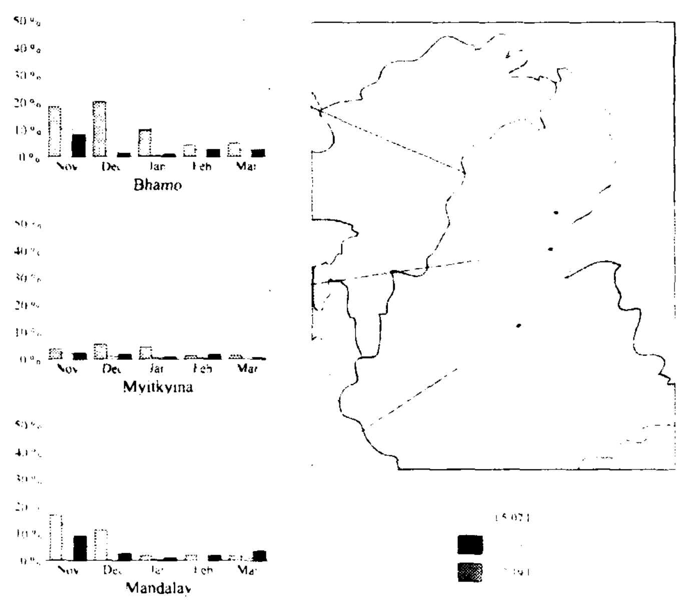


Figure 3-2. Northeast Monsoon Ceilings below 3,000 Feet. The graphs show the monthly percentage of ceilings below 3,000 feet based on location and diurnal influences.

Visibility. Figure 3-3 shows percentage of visibility below 3 miles (4,800 meters).

Central Myanmar. Under low cloud decks visibility ranges from 1 to 3 miles (1,600 to 4,800 meters) in fog near sunrise to 5 to 7 miles (8,000 meters and above) in haze in late afternoon. Above 3,000 feet (915 meters) visibility is above 10 miles (16 km). Central Myanmar frequently has early morning fog in the area of the two great rivers despite the drier conditions of the northeast monsoon. Mandalay, for instance, gets 9 days of fog in November, 17 days in December, and 18 days in January. Fog occurrence drops off sharply as the season dries even more. February and March see only 6 and 4 days of fog, respectively. The fog lifts off to short-lived broken low cloud ceilings and then dissipates completely before noon. Some haze restrictions, a combination of dust and wet haze, reduce visibility during the day to an average of 5-7 miles (8,000 meters and above).

Northern Myanmar. Under low cloud decks, visibility ranges from 1-3 miles in fog near sunrise to 5-7 miles (8,000 meters and above) in haze during late afternoon. Above 5,000 feet (1,525 meters) and clear of clouds, visibility is greater than 10 miles (16 km). Mountain stations get more fog than the rest of northern Myanmar, and it persists later into the day. In many cases this fog is actually a cloud that forms at or below the elevation of the site. Normal fog burn-off tables and calculations will not work. For example, Putao, which is located high in the mountains, has overcast cloud conditions 85 percent of the time and has fog almost 50 percent of the time. Stations in the valleys have less fog.

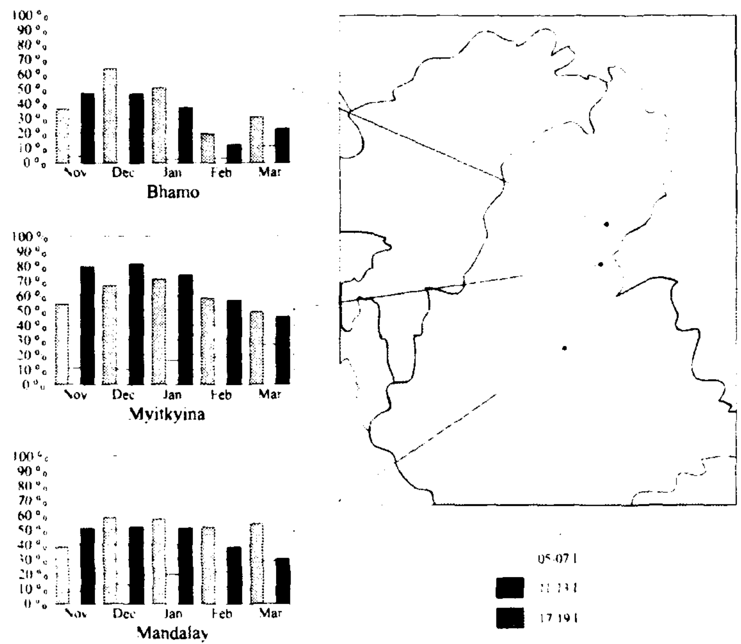


Figure 3-3. Northeast Monsoon Visibility below 3 Miles (4,800 Meters) . The graphs give a monthly breakdown of the percentage of visibility below 4,800 meters based on location and diurnal influences.

Winds. Figure 3-4 contains surface wind roses at representative locations.

Central Myanmar. Overall flow is from the north, but below 3,000 feet (915 meters) the winds reflect a mountain-valley breeze, where applicable. This is most prevalent at those locations near the Arakan Mountains, the Chin Hills, and the Shan Plateau. Late morning through early evening, winds are up-valley at 5 to 8 knots. Late evening through early morning winds are calm or down-mountain at 3 to 5 knots. The mountain-valley breeze extends upward to near the 3,000-foot (915-meter) elevation level of the mountain. Above this, the northeast monsoon winds flow uninterrupted from the north.

Northern Myanmar. Below 5,000 feet (1,525 meters), the winds reflect a marked mountain-valley breeze. Late morning through early evening winds are up-valley at 5 to 8 knots. Late evening through early morning winds are calm or down-mountain at 3 to 5 knots. Terrain always has a significant impact on wind direction and speed in this rugged area. Overall flow is from the north or northwest.

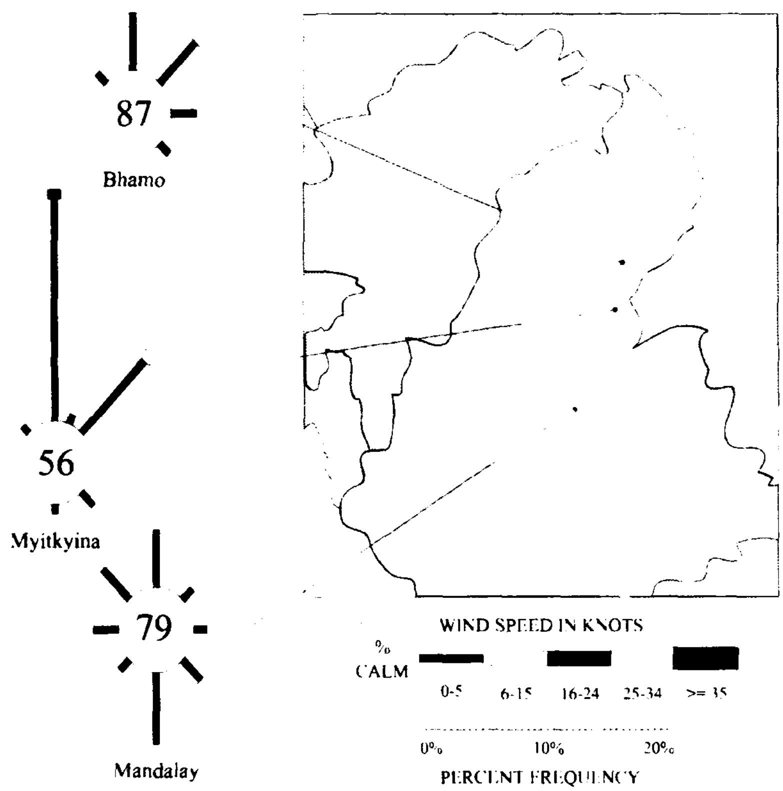


Figure 3-4. January Surface Wind Roses. The figure shows prevailing wind direction and range of speeds based on percent of frequency and location.

Upper-Level Winds. Below 5,000 feet (1,525 meters), winds flow from a generally northerly direction at 10-15 knots from December through March (see Figure 3-5). November winds below 5,000 feet (1,525 meters) still reflect the transition and are variable in direction. Terrain has considerable influence on wind direction, especially in the extremely rugged mountains of northern Myanmar. The wind stream does not smooth out until it is well above the mean mountain tops. Above 5,000 feet (1,525 meters), winds flow steadily from the northwest at 15-35 knots. A marked diurnal mountain-valley breeze exists throughout this region, extending upward to near the 5,000-foot (1,525-meter) contour of the mountains.

The jet stream slightly alters in altitude over the course of the year. It basically lies across the Himalaya Massif, although it shifts a bit south during winter and a bit north during the summer. During the northeast monsoon, peak speeds increase from a mean of 50-75 knots at approximately 35,000 feet (10,670 meters) in November to an average of 120-150 knots at approximately 30,000 feet (9,150 meters) by January. By March, the jet core has risen to approximately 40,000 feet (12,200 meters) and shifted to a position just south of the massif, its furthest south position of the year. Speeds slow again to 75-100 knots by March.

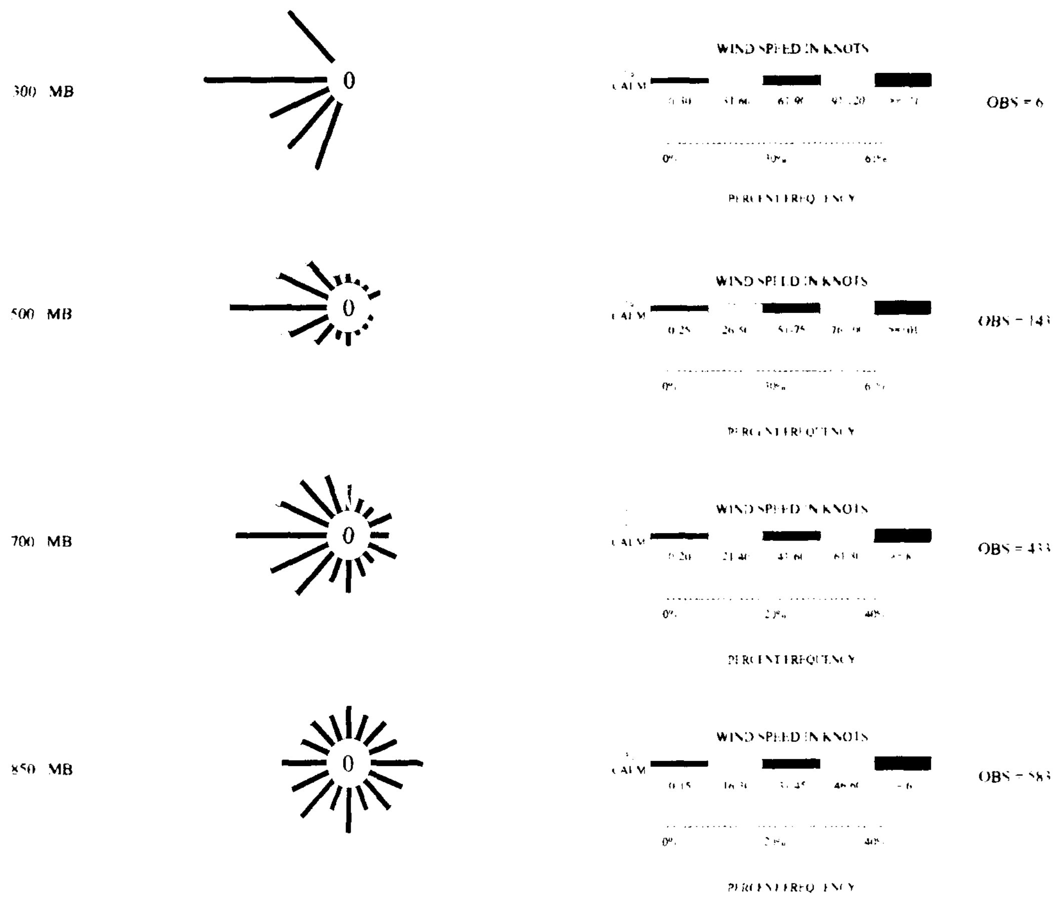


Figure 3-5. January Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 and 300 mb at Mandalay, Myanmar. Note: Each wind rose has a tailored legend.

Precipitation. Figure 3-6 shows mean precipitation amounts.

Central Myanmar. Rain and drizzle average amounts decrease from 2.5 inches (63.5 mm) in November to near zero in December, January, February, and March. Some parts of central Myanmar occasionally get more rain than others from air masses that move up from the southwest. When this rare event happens (most commonly in December), locations near the eastern face of the Shan Plateau get a short spell of upslope rain. Some places report as much as 4 to 5 inches (102-127 mm) in a single event.

Northern Myanmar. Rain and drizzle average amounts in deep valleys decrease from 1.5 inches (38 mm) in November to near zero in December and January. February and March see an increase to just under an inch (24 mm). Higher terrain, above 12,000 feet (3,660 meters), has snow. Exact precipitation amounts over higher terrain are unknown; however, amounts of 2 to 5 inches (51-127 mm) or more of precipitable water are probable. Up to 6 inches (152 mm) of rain have been recorded in northern Myanmar under the influence of Atlantic low-pressure systems (see general weather discussion).

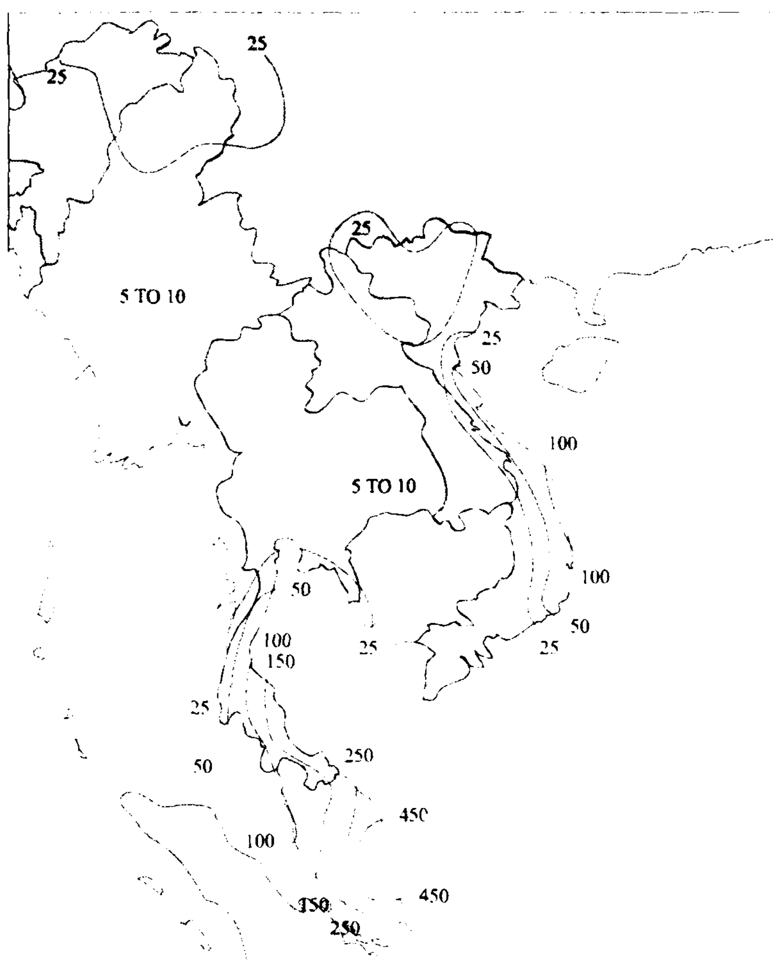


Figure 3-6. January Mean Precipitation (mm). The contours show the light precipitation amounts that occur during the northeast monsoon.

Thunderstorms. Figure 3-7 shows precipitation an thunderstorm days.

Central Myanmar. Thunderstorms do occur in this valley region; however, because orographic sinking and warming suppresses convective activity, they are rare. When these form, they normally develop along the axis of upper-air troughs or over the Chin Hills-Arakan Mountains. The thunderstorms then move eastwards in the upper-level flow. Tops reach 35,000 to 40,000 feet (10.7 to 12.2 km).

Northern Myanmar. Thunderstorms have occurred throughout this season over valley stations; however, they are rare at the lower elevations. Reports from USAAF pilots flying the "Hump" in World War II and subsequent commercial airline reports indicate that thunderstorms associated with upper-level troughs are common over ridges. As higher ridges are oriented perpendicular to the mean upper-air flow, thunderstorms lines move eastward with the trough. Tops reach 35,000 to 40,000 feet.

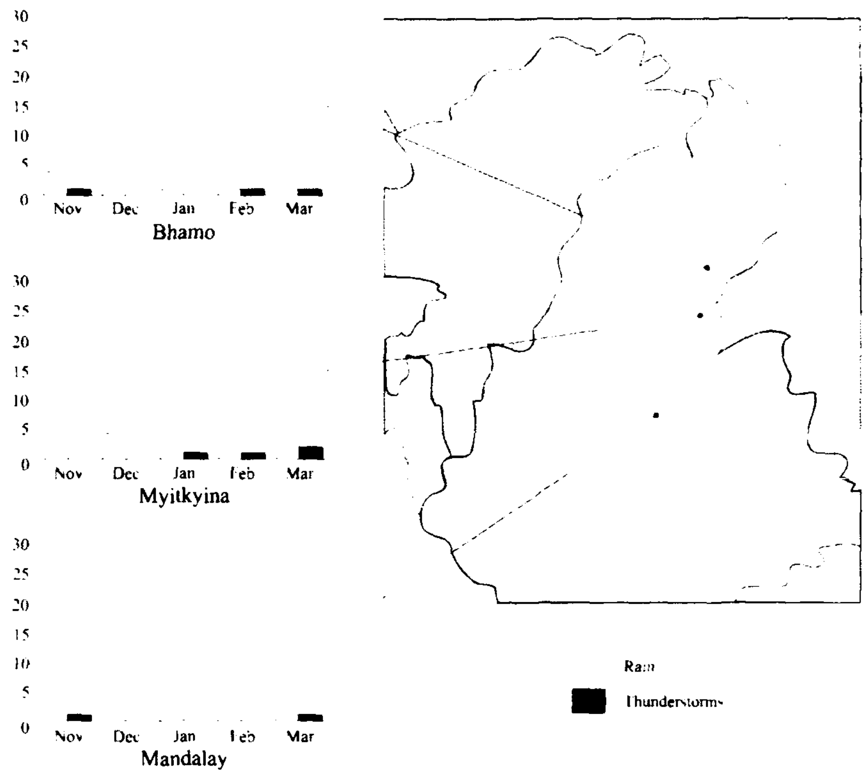


Figure 3-7. Northeast Monsoon Precipitation and Thunderstorm Days. The graphs show the average dry season occurrence of rain and thunderstorm days for selected cities in central southeast Asia.

Temperatures. Figures 3-8 and 3-9 show high and low temperature contours, respectively.

Central Myanmar. Mean maximums range in the 30° to 33°C range throughout this season. Minimums vary between 13° and 19°C. Extreme maximums in Mandalay have reached 43°C in March. The extreme minimum in Mandalay is 4°C in January during a cold outbreak; higher terrain has minimums as low as 1°C. The Arakan Yoma and Chin hills are likely to experience subfreezing temperatures for short periods during cold outbreaks.

Northern Myanmar. In deep valleys below 1,000 feet (310 meters), mean maximums range from the 24° to 26°C in December through February and rise to 28°-29°C in March. Extreme maximum temperatures dip below 38° C and stay there until March, ranging from 29° to 36°C. November through February, mean minimum temperatures are 10° to 13°C. Extreme minimums have touched 4°C at Myitkyina. Minimums at high elevations drop well below freezing on the highest peaks. The assumed lapse rate for use in mountains is 2° C per thousand feet.

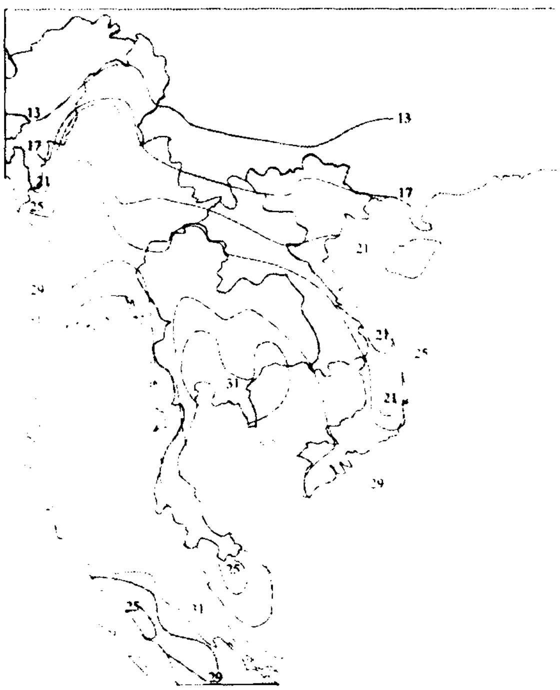


Figure 3-8. January Mean Maximum Temperatures (°C). The isopleths represent the average of all high temperatures during the dry season.

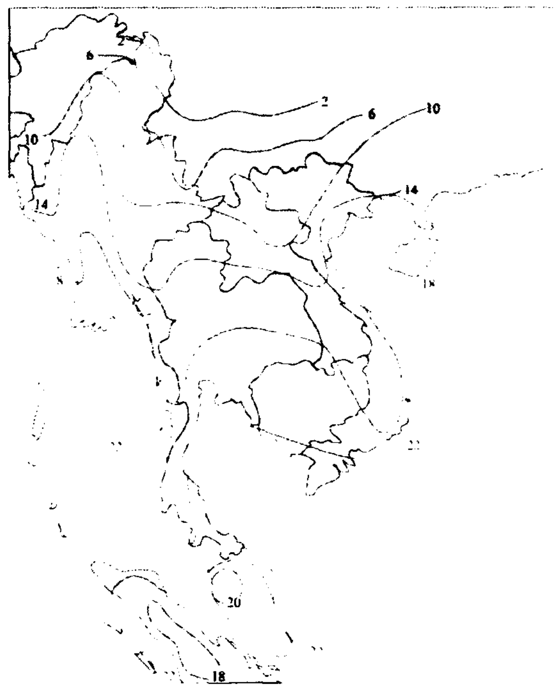


Figure 3-9. January Mean Minimum Temperatures (°C). The isopleths represent the average of all low temperatures during the dry season.

Other Hazards.

Central Myanmar. Light to occasionally moderate turbulence occurs downwind of the Arakan Mountains-Chin Hills during and just after passage of an upper trough in the westerlies. Additionally, turbulence occurs just west of the Shan Plateau mountains above 3,000 feet (915 meters) during enhanced northeasterly monsoon flow. Winds in fresh monsoon surges may reach 25 knots at ridge tops. Conversely, strong westerly to northwesterly flow may occur behind the passage of a vigorous trough aloft in the westerlies. Severe turbulence will occur near ridges under such conditions. Severe turbulence and icing are associated with thunderstorms. Moderate mixed icing is found in layered clouds above 13,000 feet (4 km) near strong upper-level troughs.

Northern Myanmar. Light to occasionally moderate turbulence occurs over ridges below 3,000 feet (915 meters). Moderate to occasionally severe turbulence occurs over ridges above 3,000 feet (915 meters) with fresh outbreaks of northeast monsoon air. Moderate to severe turbulence occurs over and near ridges above 8,000 feet (2,440 meters) in and near upper troughs. Mountains waves are common over the mountains along the Myanmar-India and Myanmar-China borders. Moderate to severe mixed icing is found in layered clouds between 12,000 feet (3,660 meters) and 20,000 feet (6.1 km) associated with troughs. Light to moderate mixed icing is found in orographic clouds between these elevations. Thunderstorms contain the usual severe mixed icing and severe turbulence.

Trafficability. Soils in this area vary from mixed fine- and coarse-grained in the north to coarse-grained in the south. The coarse-grained soils of the south are less affected by wet conditions and exhibit good to fair trafficability in most instances. In the northern areas of this subregion where mixed soils are present, the fine-grained materials reduce the stability of the coarse-grained materials during the wet season resulting in fair to poor trafficability. The more rugged topography of the north also contributes to a decrease in trafficability.

General Weather.

Central Myanmar. During late April and early May, the northeast monsoon begins to die as the Asiatic high begins to weaken. The thermal low-pressure areas over northwestern India, Pakistan, and Arabia begin to build rapidly. By late May, the Tibetan upper-level high has formed, and the upper-level westerlies south of the Himalayas have been replaced by outflow from this high. Just before the monsoon trough moves north into Myanmar, a rare tropical disturbance (below tropical storm strength) moves through the area. The monsoon trough moves rapidly northward across central Myanmar in late May and early June. The upper-level easterlies, with maximum speeds of 30 to 50 knots at 45,000 to 50,000 feet (13.7 to 15.2 km) appear by the end of May. As the monsoon trough moves north, sustained southwesterly flow is established in the lowest layers. Surface winds are channeled by terrain; Mandalay, as an example, has southerly winds averaging 5 to 6 knots. Easterlies still occur above 25,000 feet (7.6 km).

Northern Myanmar: During late April and early May, the northeast monsoon begins to die as the Asiatic high begins to weaken. The thermal low-pressure areas over northwestern India, Pakistan, and Arabia begin to build rapidly. By late May, the Tibetan upper-level high has formed; the upper-level westerlies south of the Himalayas have been replaced by outflow from this high. Just before the monsoon trough moves into Myanmar, an occasional tropical disturbance comes through, bringing early rains. These disturbances are rare and generally quite weak. The monsoon trough moves rapidly northward into northern Myanmar in late May and early June. The exact position of this trough can not be definitely fixed but an approximate mean position is near 26° N. Actual location varies as an occasional trough in the westerlies penetrates south into northern Myanmar. Rains begin earlier than in central Myanmar because of the forced lifting and squeezing effect induced by the steep terrain and the convergence associated with the monsoon trough. Upper-level winds have a preferred northeasterly direction, although westerlies and southwesterlies still occur. Speeds, in any event, average 20 to 25 knots. As the monsoon trough moves north, sustained southerly to southwesterly flow is established in the lowest layers. Surface winds are channeled by terrain; Myitkyina, as an example, still has northerly winds averaging 3 to 4 knots.

Sky Cover. Figure 3-10 (next page) shows frequency of ceilings below 3,000 feet.

Central Myanmar. Initially, conditions are similar to those of the northeast monsoon; however, south of the monsoon trough in the southwest monsoon, conditions rapidly deteriorate. Once the monsoon trough reaches the southern edge of central Myanmar (in the vicinity of the confluence of the Irrawaddy and the Chindwin), multilayers form from 2,000 to 2,500 feet MSL (610 to 760 meters) through 20,000 feet (6.1 km). Cirriform layers extend from 20,000 feet to 35,000 feet MSL (6.1 to 10.7 km). Lowest ceilings show a diurnal variation, varying from 1,200 feet (365 meters) in the early morning to 2,500 to 3,500 feet (760 to 1,070 meters) MSL in late afternoon. Ceilings at 3,000 feet or below are most common in the mornings and scatter out until after nightfall when they may reform. Ceilings below 1,500 feet (450 meters) are less usual. Peak occurrence is in the morning at 50 percent of the time. Frequency drops off to under 25 percent of the time for the remaining hours of the daylight hours. Clouds reform after nightfall and remain throughout the night an average of 35-50 percent of the time. Ceilings lower than 1,000 feet occur less than 10 percent of the time.

Northern Myanmar. Once the monsoon trough moves into Myanmar, conditions rapidly deteriorate. As the trough continues northward, deteriorating conditions spread north with and in advance of it. This is because of the orographic lifting and squeezing the air flow undergoes as it moves north into the mountainous terrain. The terrain is rugged with tremendous variability in elevation. Overcast multilayers form from 2,000 to 2,500 feet MSL (610 to 760 meters) through 20,000 feet (6.1 km). Cirriform layers extend from 20,000 feet to 35,000 feet MSL (6.1 to 10.7 km). Lowest ceilings show a diurnal variation, ranging from 1,200 feet (365 meters) in the early morning to 2,500 to 3,500 feet MSL (760 to 1,070 meters) in late afternoon. Terrain above these heights is presumed to be cloaked in cloud. Putao is locally known as the cloudiest community in Myanmar; the town has overcast low cloud ceilings 85 percent of the time, year-round. From April to October, this overcast frequently lowers to the surface. Elsewhere, ceilings between 1,500 feet and 3,000 feet (450 and 900 meters) are quite common but anything lower than that is not. As a general rule of thumb, the higher the elevation, the lower the average ceiling. Location also plays a part in this rough terrain. Places in the rain shadow of mountains have less cloud cover than windward places. Awareness of orientation, elevation, and windflow will assist in predicting cloud cover for destinations throughout northern Myanmar.

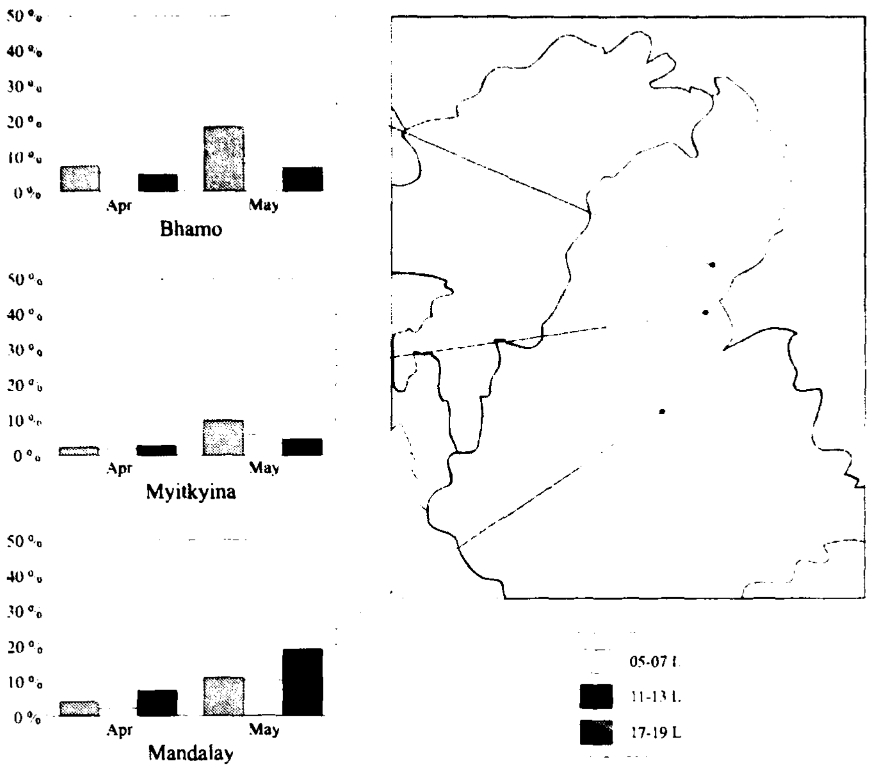


Figure 3-10. Pre-Monsoon Ceilings below 3,000 Feet. The graphs show a monthly breakdown of the percentage of ceilings below 3,000 feet based on location and diurnal influences.

Visibility. Figure 3-11 shows percentage frequency of visibility below 3 miles.

Central Myanmar. Under the low cloud decks, visibility ranges from 2 to 3 miles (3,200 to 4,800 meters) in rain. Fog is far less common in April and May than in previous months, averaging between 1 and 5 days with morning fog all throughout the valley. Visibility is less restricted as well. It falls below 3 miles (4,800 meters) less than 20 percent of the time, even in the early morning. Otherwise, visibility is only restricted to 6 miles (9,000 meters) by a light haze.

Northern Myanmar. Under the low cloud decks, visibility ranges from 2 to 3 miles (3,200 to 4,800 meters) in rain and fog. Thunderstorms can temporarily reduce visibility to under 1/2 mile (800 meters). Restricted visibility also occurs when clouds shroud mountains, but it is otherwise unrestricted. There is almost no occurrence of fog in the transition season. Precipitation causes most restrictions.

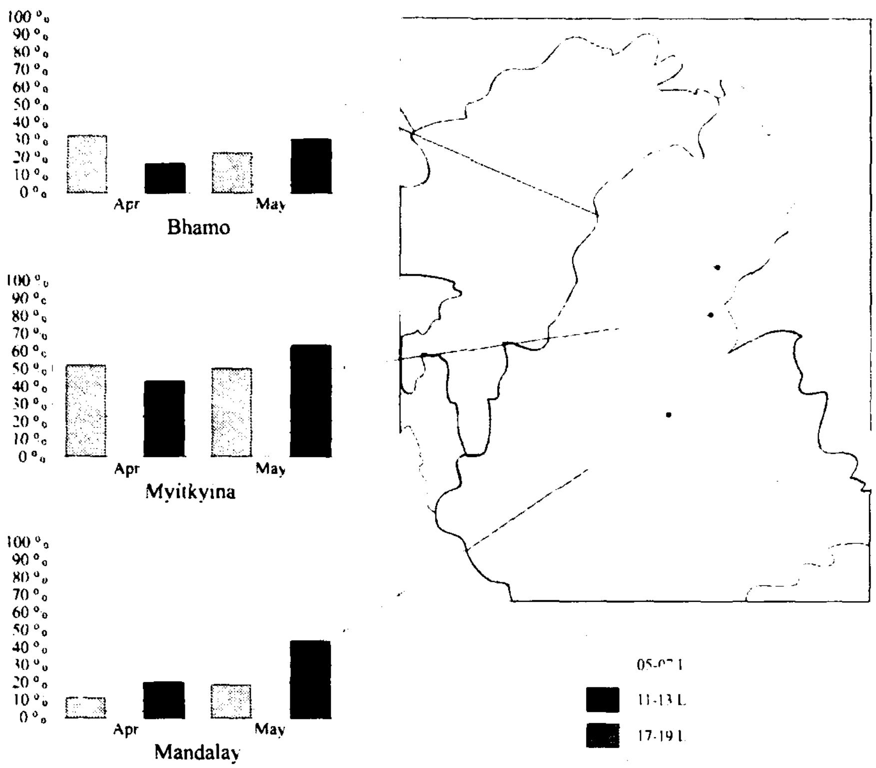


Figure 3-11. Pre-Monsoon Visibility below 3 Miles (4,800 Meters). The graphs give a monthly breakdown of the percentage of visibility below 4,800 meters based on location and diurnal influences.

Winds. Figure 3-12 shows surface wind roses at representative locations.

Central Myanmar. With northward passage of the monsoon trough in mid-May, the diurnal mountain-valley breeze characteristic of the northeast monsoon below 3,000 feet (900 meters) is replaced by the sustained southwesterly winds of the rainy season. Low-level winds average southerly to southwesterly at 5 to 10 knots. Winds at mountain ridge heights are southwesterly at 15 to 25 knots.

Northern Myanmar. Terrain always plays a role in determining wind direction in mountainous territory, and northern Myanmar is no exception to that rule. Mountain-valley breezes affect local winds. Overall flow can be forecast, but local deflections must be calculated individually. With northward movement of the monsoon trough in late-May, the sustained southwesterly winds of the rainy season replace the northerly winds of the northeast monsoon. Low-level winds average southerly to southwesterly at 5 to 10 knots. Winds at mountain ridge heights are southwesterly at 15 to 25 knots.

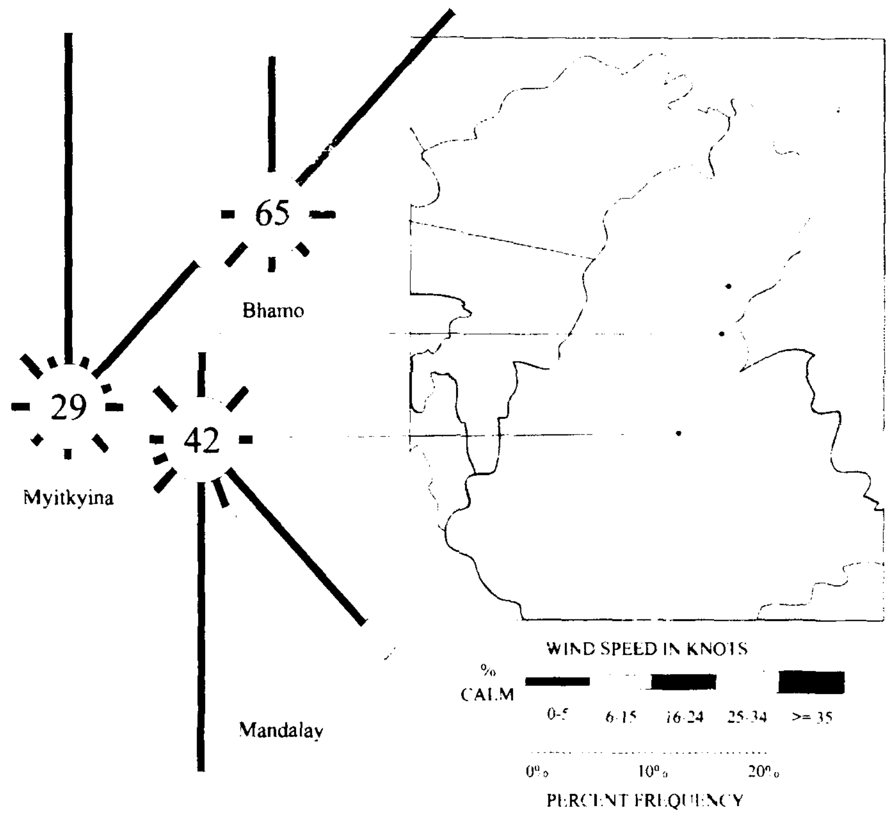


Figure 3-12. April Surface Wind Roses. The figure shows prevailing wind direction and range of speeds based on percent of frequency and location.

Upper-Level Winds. April winds begin to shift as the southwest monsoon advances northward and the northeast monsoon gives way before it. Below 5,000 feet (1,525 meters), winds are very variable; southwesterlies occur in the southern half of the region, but winds remain relatively northerly in the northern half. Speeds average 10-15 knots. Winds blow more reliably out of the northwest above 6,000 feet (1,830 meters). At 10,000 feet (3,050 meters), winds are steady from the west at 20-35 knots. By May, the winds up to 10,000 feet (3,050 meters) have definitely shifted to the southwest at 10-15 knots throughout Myanmar. Above that, they blow from the northwest at up to 30 knots outside the jet core. Although the jet moves northward, it still lies south of the Himalayan Massif and averages 50-75 knots at approximately 30,000-35,000 feet (9,150-10,670 meters). Figure 3-13 shows representative wind roses.

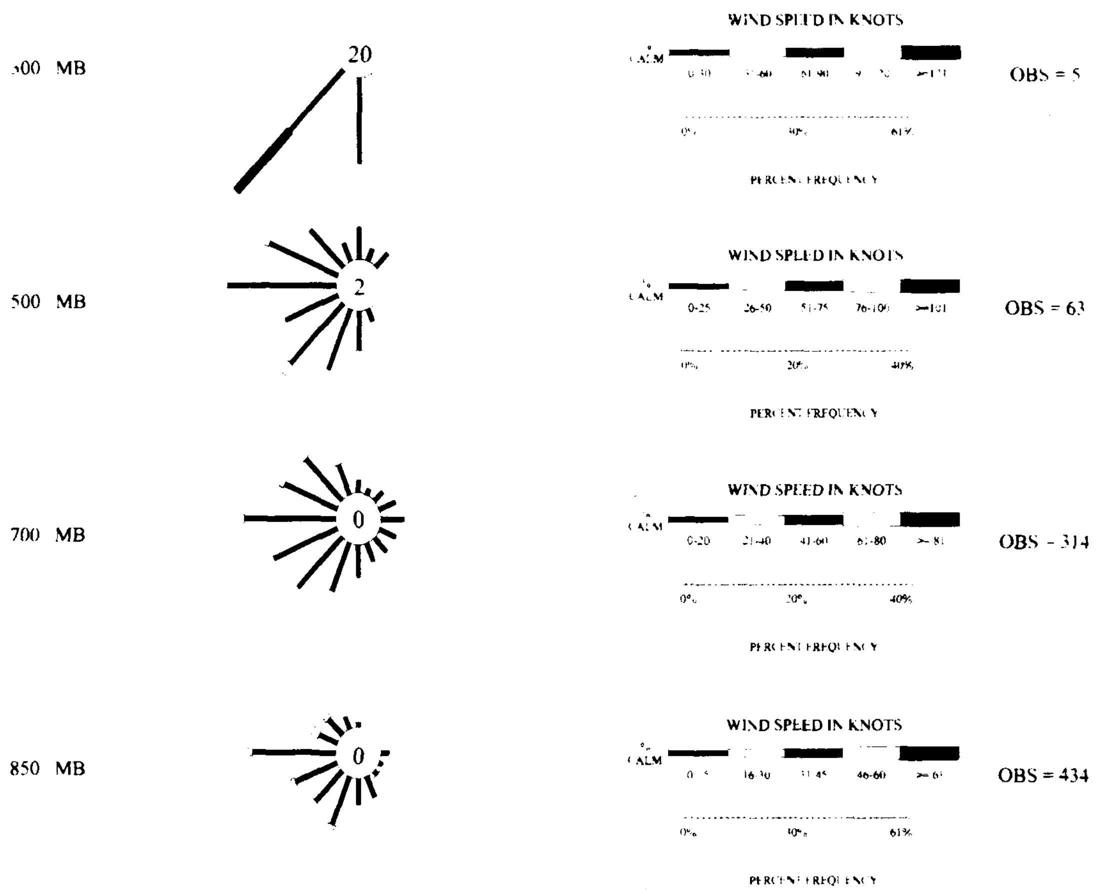


Figure 3-13. April Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 and 300 mb at Mandalay, Myanmar. Note: Each wind rose has a tailored legend.

Precipitation. Figure 3-14 shows precipitation amounts for the pre-monsoon season.

Central Myanmar. Rain and drizzle average amounts increase dramatically from just over 1 inch (25 mm) in April to almost 6 inches (152 mm) in May as the monsoon trough approaches. Extreme totals in this semiarid region have reached over 13 inches (330 mm) in May, in association with tropical disturbances and thunderstorms (as discussed in the general weather section).

Northern Myanmar. Mean rain and drizzle amounts increase from just under 2 inches (51 mm) in April to more than 6 inches (152 mm) in May. More than 18 inches (457 mm) of rain can occur when tropical disturbances combine with orographic lifting.

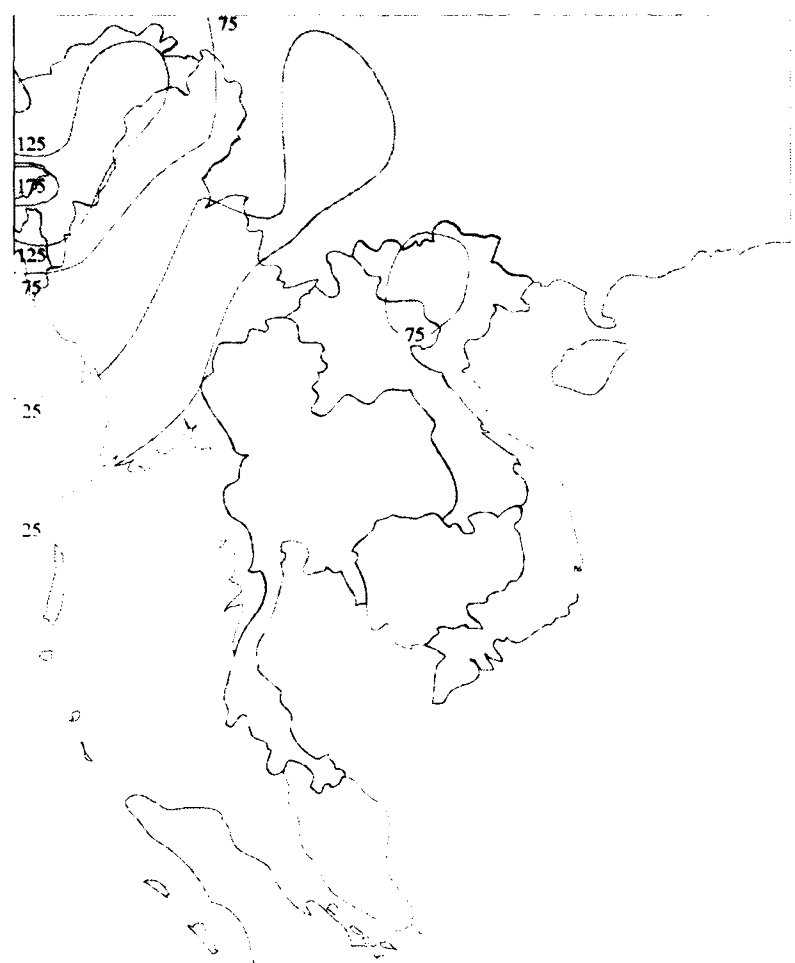


Figure 3-14. April Mean Precipitation (mm). The figure shows precipitation amounts that occur during the transition to the southwest monsoon.

Thunderstorms. Figure 3-15 shows mean number of precipitation and thunderstorm days.

Central Myanmar. Thunderstorm activity increases in the weeks just before the southwest monsoon. Maximum frequency, 13 percent, occurs during late May between 1500 and 1700L over the coastal plains. Thunderstorms over the higher mountains occur as often as 1 day in 3. Favored times are from 1200 to 1600L. Some of these thunderstorms, especially over the higher mountains, may approach severe limits. Tops range from 40,000 to 50,000 feet (12.2 to 15.2 km); isolated tops may reach 60,000 feet (18.3 km).

Northern Myanmar. Thunderstorms become increasingly frequent with the onset of the monsoon trough, reaching their peak in late May and early June. Maximum frequency, 5 percent, occurs at 1500L and 2000L. However, thunderstorms occur at any time over the mountains. Over the higher mountains, thunderstorms form almost every day, and heavy rain showers are routine occurrences. Favored times here are from 1100 to 2000L. Thunderstorms sometimes approach severe limits. Tops range from 40,000 to 50,000 feet (12.2 to 15.3 km). Isolated tops late in the pre-monsoon season may reach 60,000 feet (18.3 km).

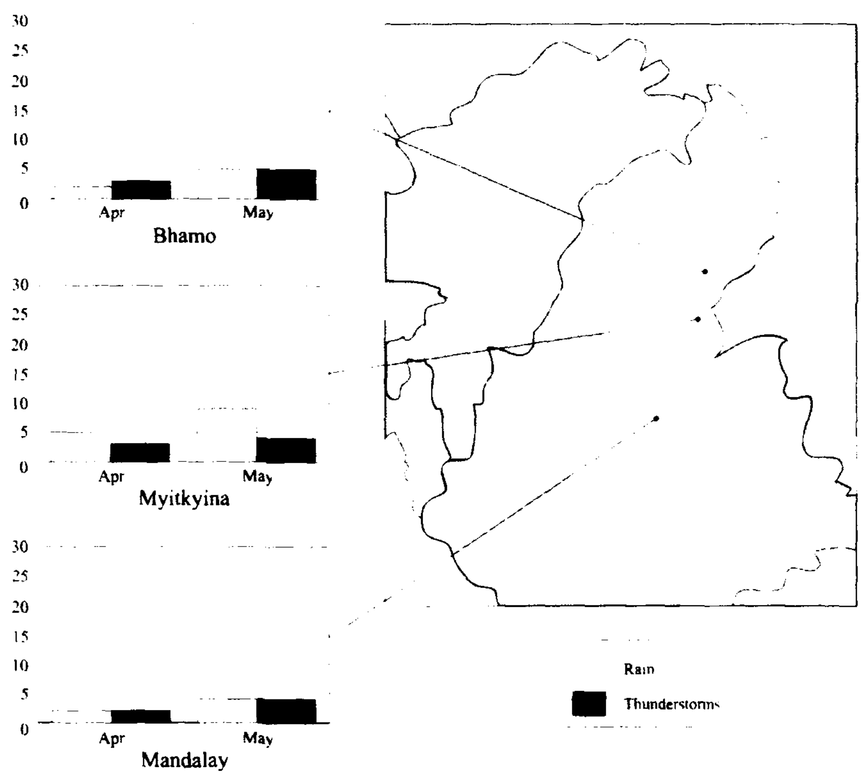


Figure 3-15. Pre-Monsoon Precipitation and Thunderstorm Days. The graphs show the number of days with rain and thunderstorms based on monthly average occurrences at scattered locations in central southeast Asia.

Temperatures. Figures 3-16 and 3-17 show mean maximum and mean minimum temperatures.

Central Myanmar. These are the last breathless, torrid days before the rains return. Maximums decrease from their yearly peak in April of 38°C to 37°C in May. Mandalay reported an extreme high temperature of 46°C in both April and May. Many stations in this area report similar extreme highs. Minimums average 25° to 26°C. Extreme minimums range between 13° and 16°C in April and 17° to 19°C in May. Mandalay fits this pattern well. It reported an extreme low of 15°C in April and 17°C in May.

Northern Myanmar. Only marginally cooler than central Myanmar, northern Myanmar is still extremely hot in these last days before the southwest monsoon. Maximums in valley stations below 1,000 feet (310 meters) MSL reach 32°-34°C in both April and May. Extreme maximums have reached 42°C in Bhamo and 43°C in Myitkyina. Minimums fall to the 19° to 21°C and 21° to 23°C range, respectively. Extreme minimums range from 10°C in April to 13°C in May. Bhamo reported those extreme minimum temperatures, but they represent conditions in the area except, of course, for the high elevations where it gets considerably cooler. The freezing level rises to 15,000 feet (4.6 km) in May. A temperature decrease of 2.2°C per 1,000 feet (310 meters) should be used to compute temperatures at intermediate elevations.

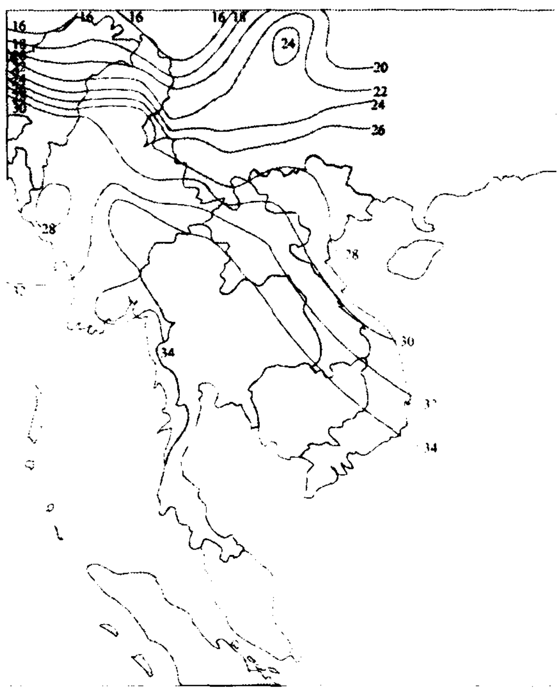


Figure 3-16. April Mean Maximum Temperatures (°C). The isopleths represent the average of all high temperatures during the dry season.

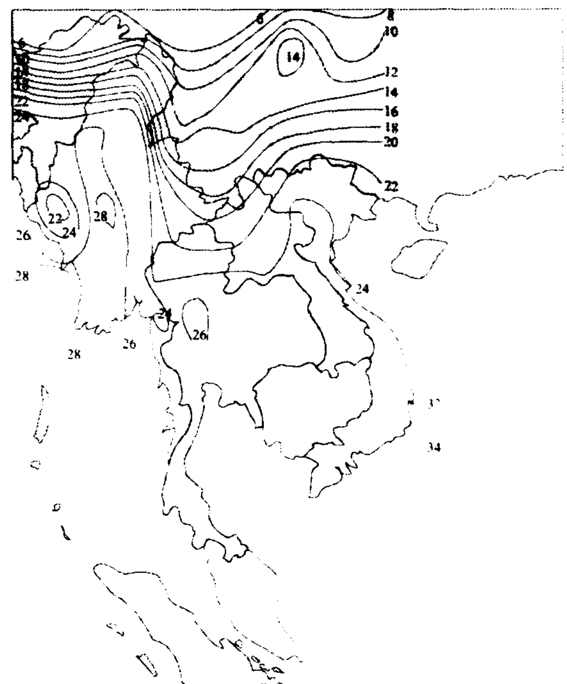


Figure 3-17. April Mean Minimum Temperatures (°C). The isopleths represent the average of all low temperatures during the dry season.

Other Hazards.

Central Myanmar. Light to occasionally moderate turbulence occurs over the mountains; light to occasionally moderate mixed icing occurs above 16,000 feet (4.9 km). Severe mixed icing and turbulence occur in and near thunderstorms. Icing is confined to heights above 16,000 feet (4.9 km); turbulence occurs at any level. Turbulence hazards are increased by the combination of thunderstorm downdrafts and mountainous terrain. Moderate mixed icing also occurs above 15,000 feet MSL (4.6 km) in the layered clouds of the southwest monsoon. Moderate turbulence occurs over the Chin Hills-Arakan Mountains region southwesterly flow.

Northern Myanmar. Light to occasionally moderate turbulence occurs over the mountains; light to occasionally moderate mixed icing occurs above 16,000 feet (4.9 km). Severe mixed icing and turbulence occur in and near thunderstorms. Icing is confined to heights above 16,000 feet (4.9 km); turbulence occurs at any level. Turbulence hazards are increased by the combination of thunderstorm downdrafts and mountainous terrain. Moderate mixed icing also occurs above 15,000 feet MSL (4.6 km) in the layered clouds of the southwest monsoon. Moderate turbulence occurs over and in the lee of most ridges lines having mean maximum elevations above 5,000 feet (1,500 meters) MSL.

Trafficability. Soils in this area vary from mixed fine- and coarse-grained in the north to coarse-grained in the south. The coarse-grained soils of the south are less affected by wet conditions and exhibit good to fair trafficability in most instances. In the northern areas of this subregion where mixed soils are present, the fine-grained materials reduce the stability of the coarse-grained materials during the wet season resulting in fair to poor trafficability. The more rugged topography of the north also contributes to a decrease in trafficability.

General Weather.

Central Myanmar. The monsoon trough stabilizes over northern Myanmar. Orographic subsidence is no longer enough to suppress all precipitation in central Myanmar. The overall southwesterly flow contains so much moisture that even this semiarid place gets rainfall. This season sees the passage of the remains of an occasional tropical disturbance from Indochina. Frequencies are low, averaging 1 disturbance per month, and the systems rarely ever achieve tropical storm strength. Conditions are those typical of the southwest monsoon.

Northern Myanmar. The monsoon trough stabilizes over northern Myanmar; however, occasional deep troughs in the westerlies flowing across central Asia still penetrate into this region even at the peak of the southwest monsoon. An occasional tropical disturbance from the South China Sea and Indochina moves into Myanmar, on average, once or twice a month. These weak storms enhance the existing conditions of the southwest monsoon regime, bringing even more rain into Myanmar, especially in the north.

Sky Cover. Figure 3-18 shows percent frequency of ceilings below 3,000 feet.

Central Myanmar. Multilayers form from 2,000 to 2,500 feet MSL (600 to 800 meters) through 20,000 feet (6.1 km). Cirriform layers extend from 20,000 feet to 35,000 feet MSL (6.1 to 10.7 km). Lowest ceilings show a diurnal variation, varying from 1,200 feet (365 meters) in the early morning to 2,500 to 3,500 feet MSL (760 to 1,070 meters) in late afternoon. Ceilings below 3,000 feet (900 meters) occur an average of 25-35 percent of the time throughout the day, but ceilings at or below 1,500 feet occur only 10 percent of the time or less.

Northern Myanmar. Overcast multilayers form from 2,000 to 2,500 feet MSL (610 to 760 meters) through 20,000 feet (6.1 km). Cirriform layers extend from 20,000 feet to 35,000 feet MSL (6.1 to 10.7 km). Lowest ceilings show a diurnal variation from 1,200 feet (365 meters) in the early morning to 2,500 to 3,500 feet MSL (760 to 1,070 meters) in late afternoon. Due to the ruggedness of the area, all cloud heights and ceilings are MSL; terrain above these heights is presumed to be in cloud. Ceilings below 3,000 feet occur 50 to 65 percent of the time throughout northern Myanmar. Ceilings below 1,500 feet (450 meters) occur more frequently here than in central Myanmar. These ceilings occur 50 to 65 percent of the time. Locations in rainshadows have higher cloud bases. Windward sites are often blanketed in cloud, especially those at higher elevations. Knowledge of terrain and windflow is critical to predicting cloud cover in this zone.

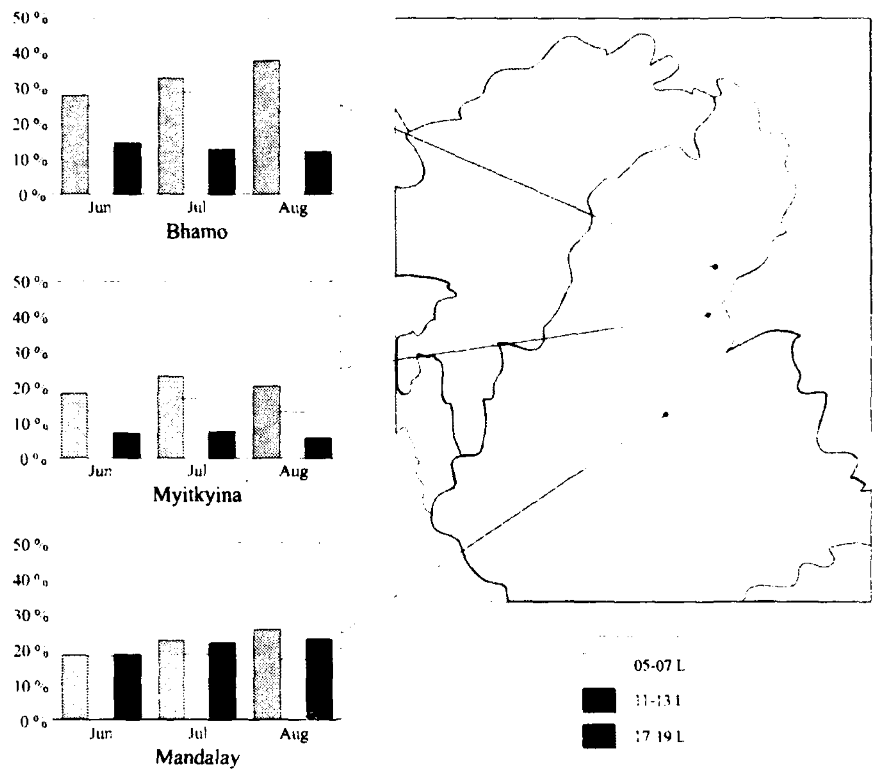


Figure 3-18. Southwest Monsoon Ceilings below 3,000 Feet. The graphs show a monthly breakdown of the percentage of ceilings below 3,000 feet based on location and diurnal influences.

Visibility. Figure 3-19 shows the percent frequency of visibility below 3 miles (4,800 meters).

Central Myanmar. Under low cloud decks, visibility ranges from 2 to 3 miles (3,200 to 4,800 meters) in rain. Fog does not occur during this season. Thunderstorms can reduce visibility to under 1/2 mile (800 meters) for a short time, but overall visibility is 6 miles (9,000 meters) of better. Fog occurs less than 1 day for the entire season. Visibility is most restricted by rain and rain showers.

Northern Myanmar. Visibility ranges from 2 to 3 miles (3,200 to 4,800 meters) in rain. Although rain frequently restricts visibility, fog is far less common. Fog occurs less than 1 day per month. Thunderstorms can reduce visibility to under 1/2 mile (800 meters) for a short time; however, visibility normally exceeds 6 miles (9,000 meters).

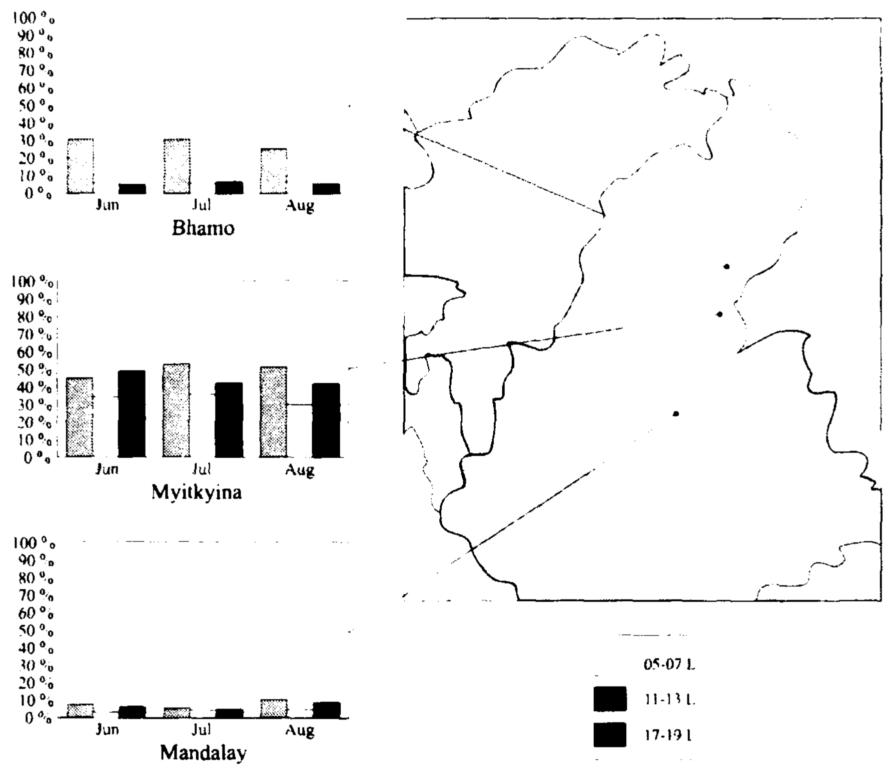


Figure 3-19. Southwest Monsoon Visibility below 3 Miles (4,800 Meters). The graphs give a monthly breakdown of the percentage of visibility below 4,800 meters based on location and diurnal influences.

Winds. Figure 3-20 shows surface wind roses at repiesentative locations.

Central Myanmar. Low-level winds average south to southwest at 5 to 10 knots. Stations closer to the eastern face of the Shan Plateau have southeast winds due, in part to deflection around Pegu Yoma, and partly because of the plateau itself. Mandalay is an example of this with winds from the southeast from March to October. Winds at mountain ridge heights are southwesterly at 15 to 25 knots. Once or twice a month, the remains of tropical disturbances that have moved across Indochina and Thailand cross into the Andaman Sea. These disturbances are almost never sufficiently organized to cause appreciable changes in low-level wind patterns. They behave very similarly to easterly waves in the Caribbean.

Northern Myanmar. Surface winds are channeled by terrain. As an example, Myitkyina has southeast winds averaging 3 to 4 knots. Meanwhile, Bhamo, which is oriented differently, has southwest winds at about the same speed. Mountain-valley breezes are never completely overpowered by the southwest monsoon winds, so direction can be highly variable and is dependent on terrain and position relative to mountains and valleys.

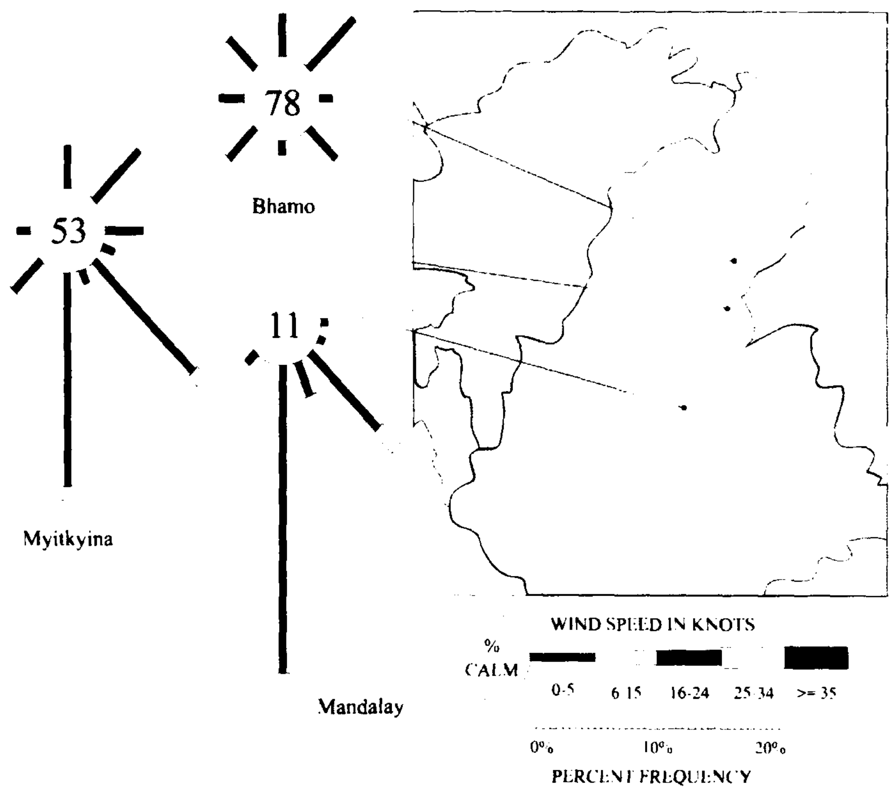


Figure 3-20. July Surface Wind Roses. The figure shows prevailing wind direction and range of speeds based on percent of frequency and location.

Upper-Level Winds. Figure 3-21 shows upper-air wind roses for representative locations.

Central Myanmar. Deep, sustained southwesterly flow exists all the way from the ground up to 20,000 feet (6,100 meters). Speeds average 10 to 15 knots at the surface and increase to between 25 and 35 knots at 20,000 feet (6,100 meters). Above this level, the easterlies average 25 to 45 knots.

Northern Myanmar. Mean winds are southwesterly at 10 to 15 knots south of 26° N, increasing to 25-35 knots from the same direction above 20,000 feet (6.1 km). Winds at 5,000 feet (1,525 meters) are southwesterly at 15 to 25 knots. Winds above 20,000 feet (6.1 km) become easterly at 20 to 30 knots, as the southwest monsoon moves to its most northerly position. By this time, the jet stream is well north of Myanmar and lies over the northern part of the Himalayas. Deep easterlies of 35-45 knots prevail over Myanmar to well above 45,000 feet (13,700 meters).

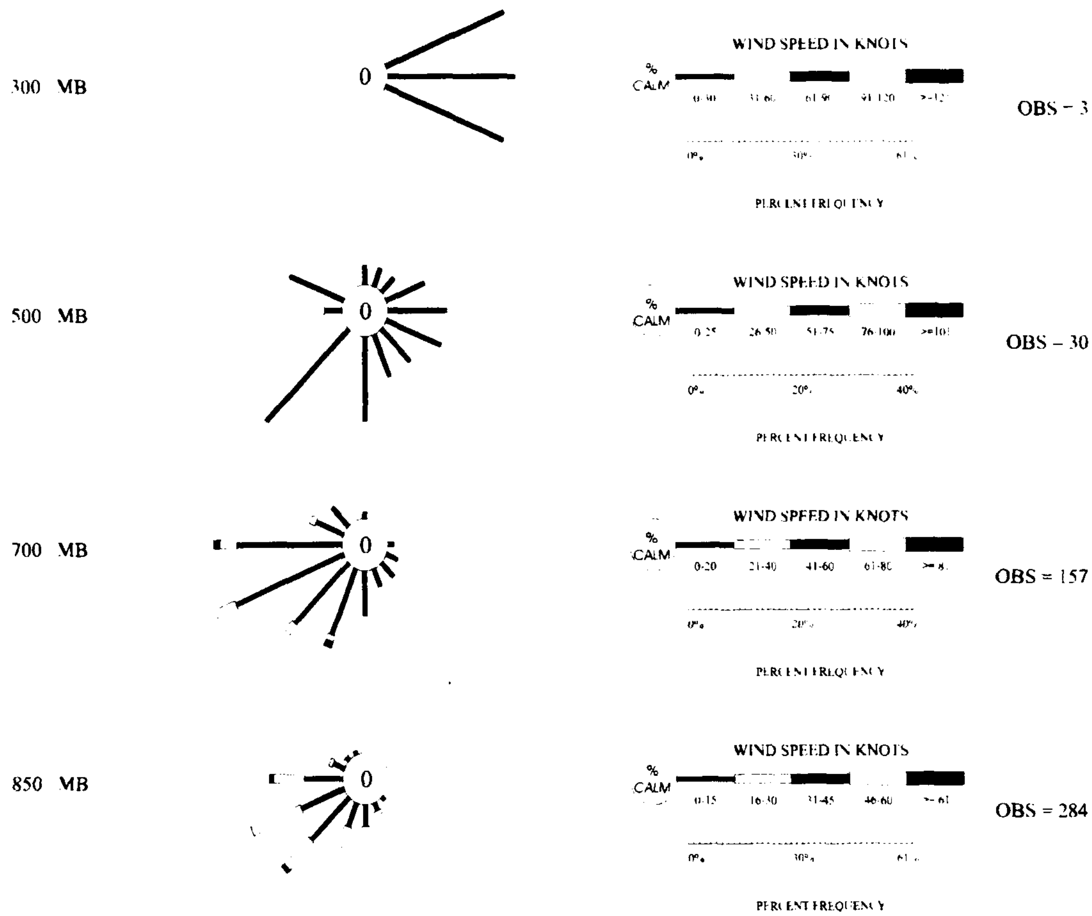


Figure 3-21. July Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 and 300 mb at Mandalay, Myanmar. Note: Each wind rose has a tailored legend.

Precipitation. Figure 3-22 shows mean precipitation amounts for July.

Central Myanmar. Mean monthly rain and drizzle amounts range between 4.5 to 6 inches (114-152 mm) for most of the southwest monsoon season. July shows a slight decrease to means between 2 and 3 inches (51-76 mm), but the amounts pick up again in August. This slight dry-out appears to be caused by a shift in wind direction to a more westerly component that cuts off some of the moisture. Maximum totals have reached more than 15 inches (381 mm) in both July and August in association with tropical disturbances and thunderstorm activity.

Northern Myanmar. Monthly mean precipitation amounts are high, ranging between 17 and 19 inches (432 [illegible]3 mm). Myitkyina totals have exceeded 38 inch[illegible] 965 mm) in June and approached the same in July, mostly in association with tropical disturbance-enhanced southwest monsoonal precipitation. Tropical precipitation peaks near the 5,000-foot (1,500-meter) contour in mountainous regions; mean monthly amounts of 25 to 30 inches (635-762 mm) are probable.

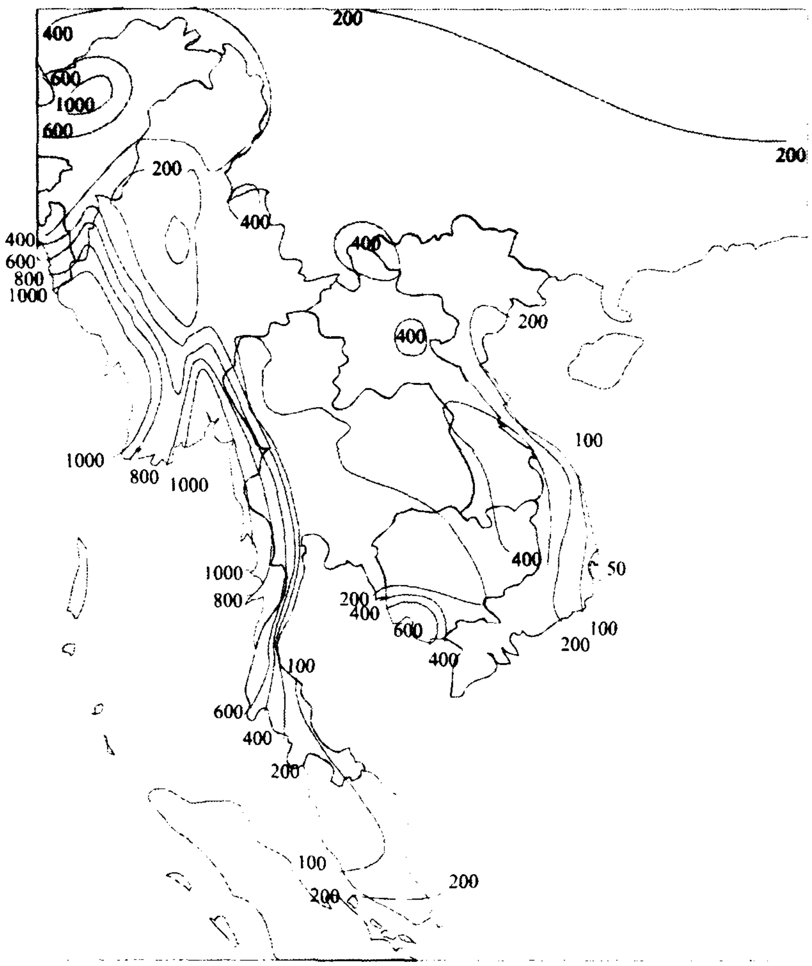


Figure 3-22. July Mean Precipitation (mm). The contours shows mean precipitation totals for central southeast Asia.

Thunderstorms. Figure 3-23 shows mean precipitation and thunderstorm days.

Central Myanmar. Thunderstorms occur with progressively less frequency, although they occur throughout the entire southwest monsoon season. Maximum frequency—4 to 5 percent occurs between 1500 and 1700L. Some of these thunderstorms, especially over the higher mountains, approach severe limits. Tops range from 40,000 to 50,000 feet (12.2 to 15.3 km); isolated tops late in the pre-monsoon season may reach 60,000 feet (18.3 km).

Northern Myanmar. July thunderstorm activity drops slightly from maximums in late May and early June in the northern Myanmar lowlands, but shows no decrease in the mountains. It increases again in August. Maximum frequency, 11 percent, occurs between 1500 and 2000L. This does not limit thunderstorms just to those hours. They occur at any time over the mountains. Thunderstorms occur over the higher mountains as often as 1 day in 3 for most of the season. At the peak of the southwest monsoon, thunderstorms are almost a daily occurrence in the mountainous areas. Favored times here are from 1100 to 2000L. Some of these thunderstorms, especially over the higher mountains, approach severe limits. Tops range from 40,000 to 55,000 feet (12.2 to 16.7 km); isolated tops may reach 60,000 feet (18.3 km). The exception to the July drop in occurrence is thunderstorm activity associated with tropical disturbances, which enhance the normal southwest monsoon rains. Thunderstorms that develop in those circumstances are heavy and drop significant amounts of rain (6 to 8 inches (152-203 mm) in a single shower).

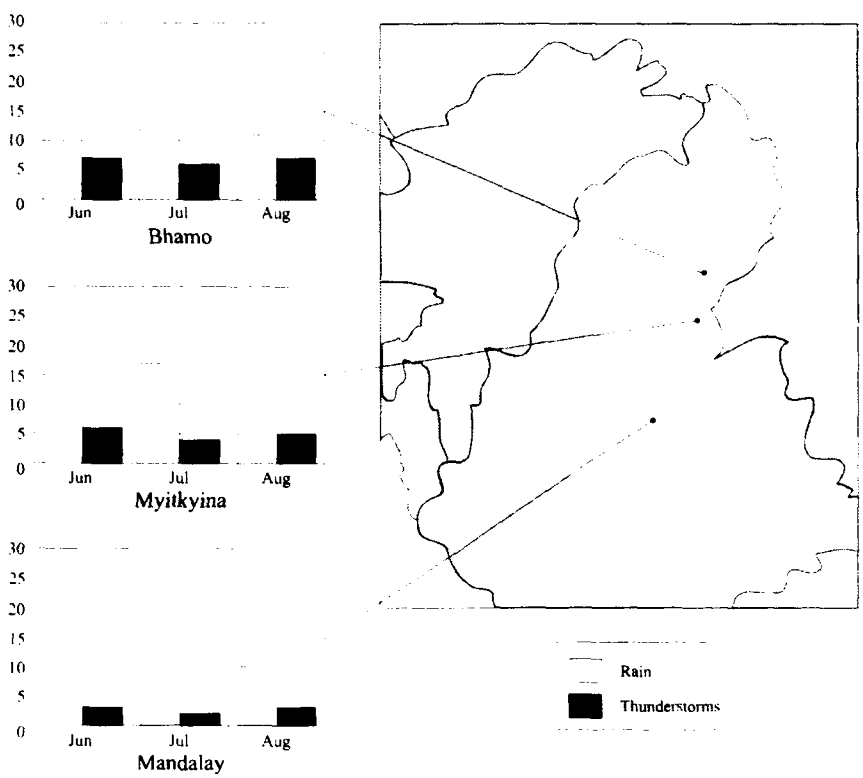


Figure 3-23. Southwest Monsoon Precipitation and Thunderstorm Days. The graphs show the average wet season occurrence of rain and thunderstorm days for selected cities in central southeast Asia.

Temperatures. Figures 3-24 and 3-25 show mean maximum and minimum temperatures.

Central Myanmar. Although the increase in humidity makes it feel hotter than ever, temperatures cool down under the southwest monsoon. Maximum temperatures are in the 32°-35°C. Minimums hover in the 26° to 28°C range. Extreme maximums have reached 42°C in Mandalay during monsoon breaks. Extreme minimums barely drop below 21°C. Mandalay reported an extreme low of 19°C in August.

Northern Myanmar. Maximums in valley stations below 1,000 feet (310 meters) MSL hover in the 30°-31°C range all season. June has the highest extreme high temperature of the season. Bhamo reported 41°C in June, but temperatures topping 38°C are fairly normal for the area throughout the season. Mean minimums are commonly 23°-25°C. Extreme minimums range near 17°-20°C except in the high mountains. The freezing level rises to 15,000 feet (4.6 km) in May. A temperature decrease of 2.2°C per 1,000 feet (310 meters) should be used to compute temperatures at intermediate elevations.

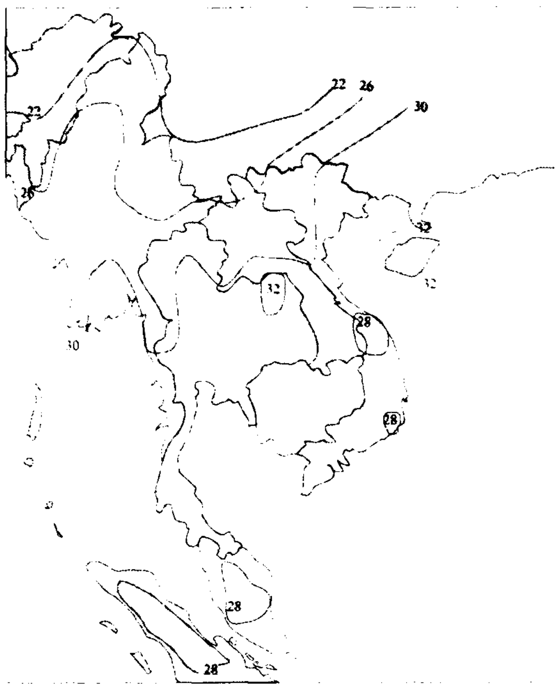


Figure 3-24. July Mean Maximum Temperatures (°C). The isopleths represent the average of all high temperatures during the dry season.

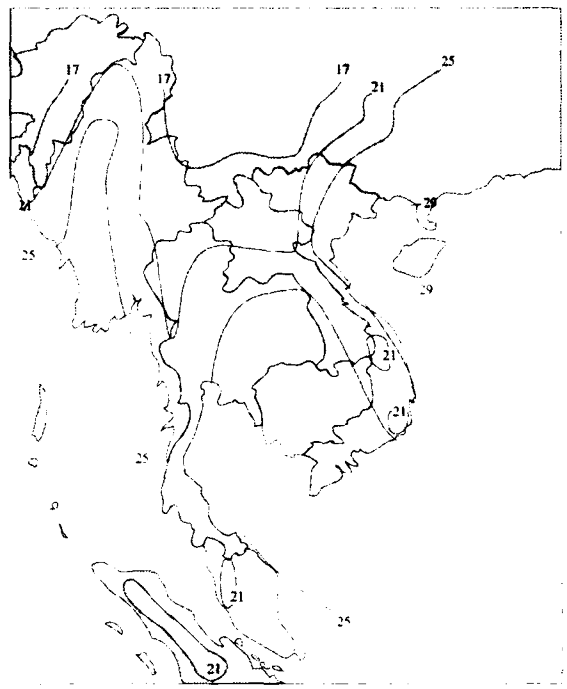


Figure 3-25. July Mean Minimum Temperatures (°C). The isopleths represent the average of all low temperatures during the dry season.

Other Hazards.

Central Myanmar. Light to occasionally moderate turbulence occurs over the mountains; light to occasionally moderate mixed icing occurs above 16,000 feet (4.9 km). Severe mixed icing and turbulence occur in/near thunderstorms. Icing is confined to heights above 16,000 feet (4.9 km); turbulence occurs at any level. Turbulence hazards are increased by the combination of thunderstorm downdrafts and mountainous terrain. Moderate mixed icing also occurs above 15,000 feet MSL (4.6 km) in the layered clouds of the southwest monsoon. Moderate turbulence occurs over the Chin Hills-Arakan Mountains region in southwesterly flow.

Northern Myanmar. Light to occasionally moderate turbulence occurs over the mountains; light to occasionally moderate mixed icing occurs above 16,000 feet (5 km). Severe mixed icing and turbulence occur in/near thunderstorms. Icing is confined to heights above 15,000 feet (4.6 km); turbulence occurs at any level. Turbulence hazards are increased by the combination of thunderstorm downdrafts and mountainous terrain. Moderate mixed icing also occurs above 15,000 feet MSL (4.6 km) in the layered clouds of the southwest monsoon. Moderate turbulence occurs over and in the lee of most ridges lines having mean maximum elevations above 5,000 feet (1,500 meters) MSL. While flooding is a hazard in any season, the southwest monsoon season is the prime time for all of Myanmar. Heavy thunderstorms can dump large amounts of rain in a very short period and cause flash flooding. Many roads are no more than dirt tracks that turn into seas of mud. Of course, with such mountainous terrain, washouts and mudslides should be anticipated.

Trafficability. Soils in this area vary from mixed fine- and coarse-grained in the north to coarse-grained in the south. The coarse-grained soils of the south are less affected by wet conditions and exhibit good to fair trafficability in most instances. In the northern areas of this subregion where mixed soils are present, the fine-grained materials reduce the stability of the coarse-grained materials during the wet season resulting in fair to poor trafficability. The more rugged topography of the north also contributes to a decrease in trafficability.

General Weather.

Central Myanmar. The monsoon trough moves south of this area by the middle of September. Before the trough moves south, southwestern monsoon conditions prevail; afterward, northeast monsoon conditions quickly take over. There is a distinct drop in precipitation in September, which becomes even more pronounced in October. Winds shift around from a southeast flow to north flow in September. While the trough is still relatively close, an occasional tropical disturbance rides the trough and causes it to wave northward. This brings in large amounts of rainfall an average of once in September, but the threat is over by October.

Northern Myanmar. As the monsoon trough moves south, weather conditions improve rapidly in a progression from north to south. Occasional westerly low-pressure systems begin to develop and move through northern Myanmar after passing over India and Pakistan. This occurs an average of once per month in both September and October but is more likely in October than September. Weak northeasterly flow from across the South China Sea (originates as cold outbreaks from Siberia) begins to develop and reach into northern Myanmar by late October. Although they begin life as continental polar air masses, the long trajectory over land and water modifies the northeasterlies.

Sky Cover. Figure 3-26 shows percent frequency of ceilings below 3,000 feet.

Central Myanmar. Initially, conditions continue to be similar to those of the southwest monsoon. North of the monsoon trough, however, as the northeast monsoon advances south, conditions rapidly improve. The only clouds in the upper-level flow are cirriform decks and an occasional middle cloud deck associated with the southern end of a strong trough in the westerlies. Nocturnal low clouds form 55 percent of the time by late evening and dissipate by midmorning. Scattered to broken stratus and stratocumulus layers, with bases 2,000 feet (610 meters) MSL and tops between 2,500 and 3,000 feet (760 and 915 meters) MSL, form by late evening. Mountains between 800 and 2,500 feet (245 and 760 meters) are obscured. These lower clouds clear by noon. Ceilings below 3,000 feet occur about 25-35 percent of the time, but ceilings at and below 1,500 feet (450 meters) are much less common.

Northern Myanmar. Conditions improve rapidly as the southwest monsoon gives way to the northeast monsoon. Typical northeast monsoon conditions appear very early in the transition as the trough shifts quickly south. Extensive middle cloud and cirriform decks are associated with troughs in the westerlies. Multiple layers extend up to 30,000 to 35,000 feet (9.1 to 10.7 km). Broken to near-overcast (5/8-7/8) low clouds shroud ridges and canyons between 2,000 and 5,000 feet (610 and 1,500 meters) up to 65 percent of the time, dissipating to scattered (2/8-4/8) cover in afternoons only where canyons are wide enough to permit substantial heating. Mountain slopes between 2,000 and 5,000 feet (610 and 1,500 meters) are normally obscured except during early evening when downslope winds may be sufficient to temporarily clear the low cloud decks. Except in higher elevations, clouds below 1,500 feet (450 meters) occur under 15 percent of the time.

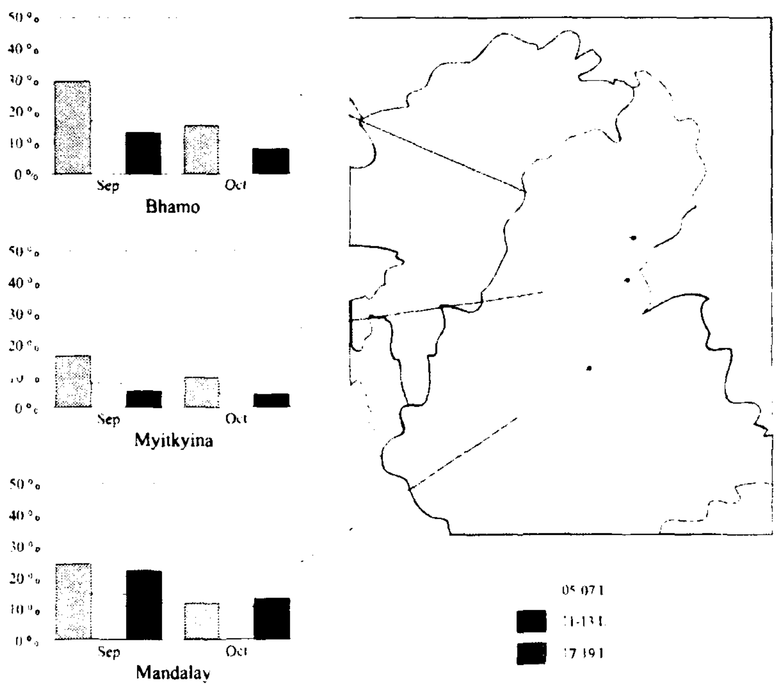


Figure 3-26. Post-Monsoon Ceilings below 3,000 Feet. The graphs show a monthly breakdown of the percentage of ceilings below 3,000 feet based on location and diurnal influences.

Visibility. Figure 3-27 shows percent frequency of visibility below 3 miles (4,800 meters).

Central Myanmar. Until the trough passes south, visibility under low cloud co nges between 2 and 3 miles (3,200 and 4,800), and 5-6 miles (8,000-9000 meters) in wet haze otherwise. Conditions after monsoon trough passage southward range from 1 to 3 miles (1,600 and 4,800 meters) in early morning haze to better than 6 miles (9,000 meters) in haze during the afternoon. Fog occurs between 1 and 3 days in September, depending on proximity to the rivers. The frequency rises a bit in October, but it still remains low, between 4 and 7 days of the month.

Northern Myanmar. Conditions under low cloud decks continue to limit visibility to 1-3 miles (1,600 to 4,800 meters) in rain and drizzle. This is typical of the mountain slopes and high valley areas of northern Myanmar. Outside of adverse weather, visibility improves to 5 miles (8,000 meters) or better in haze during the afternoon hours. Above 5,000 feet (1,500 meters) and clear of clouds, visibility is unlimited. In lower valleys, there is less visibility restriction unless an organized weather system such as a late season westerly or an early season easterly wave moves through. Fog occurs an average of 3-6 days per month in the area except for high elevation sites. Those sites have more apparent fog, but it is more cloud than any actual type of fog. The rules for predicting visibility in fog situations would not apply to these areas.

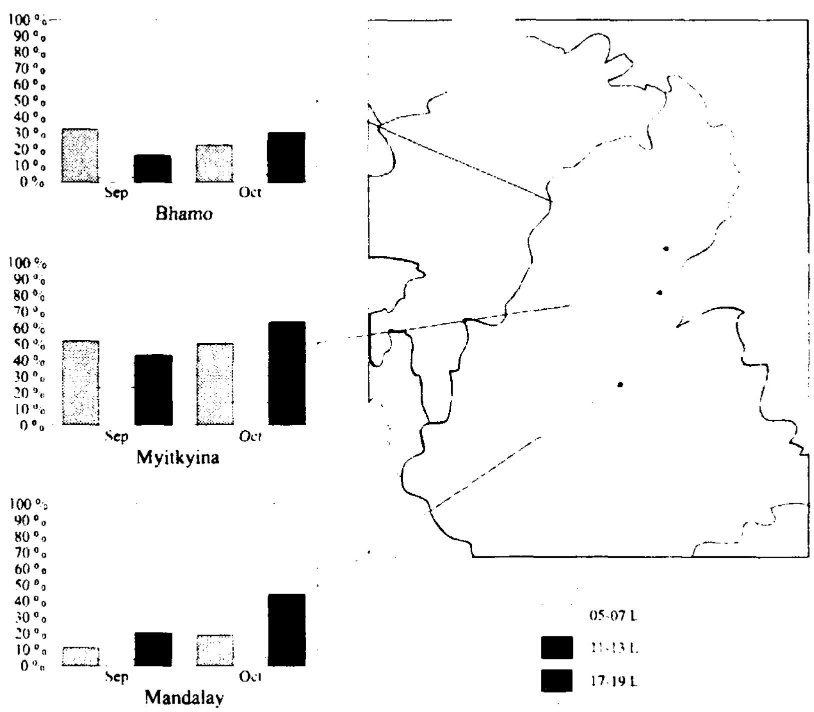


Figure 3-27. Post-Monsoon Visibility below 3 Miles (4,800 Meters). The graphs give a monthly breakdown of the percentage of visibility below 4,800 meters based on location and diurnal influences.

Winds. Figure 3-28 shows surface wind roses at representative locations.

Central Myanmar. Before the monsoon trough moves south, sustained southwesterly flow averages 10 to 15 knots at the surface. This flow reaches up 20,000 feet (6.1 km); above this level, the easterlies flow unchecked. Once the trough moves south, northeasterly flow establishes itself. The primary flow pattern, however, becomes a marked diurnal mountain-valley breeze. The mountains and plateau that sandwich this area cause the breeze. Low-level winds average 5 to 10 knots and the direction is very terrain dependent. In Mandalay, winds remain southeasterly through the transition. Winds at mountain ridges are southwesterly at 15 to 25 knots.

Northern Myanmar. Variable flow, dominated by mountain-valley breezes, becomes predominant in the lowest layers. Surface winds are channeled by terrain; Myitkyina has northerly winds averaging 3 to 4 knots while Bhamo's winds are more northeasterly. Below 5,000 feet (1,500 meters), the winds reflect a mountain-valley breeze. Late morning through early evening winds are up-valley at 5 to 8 knots. Late evening through early morning winds are calm or down-mountain at 3-5 knots.

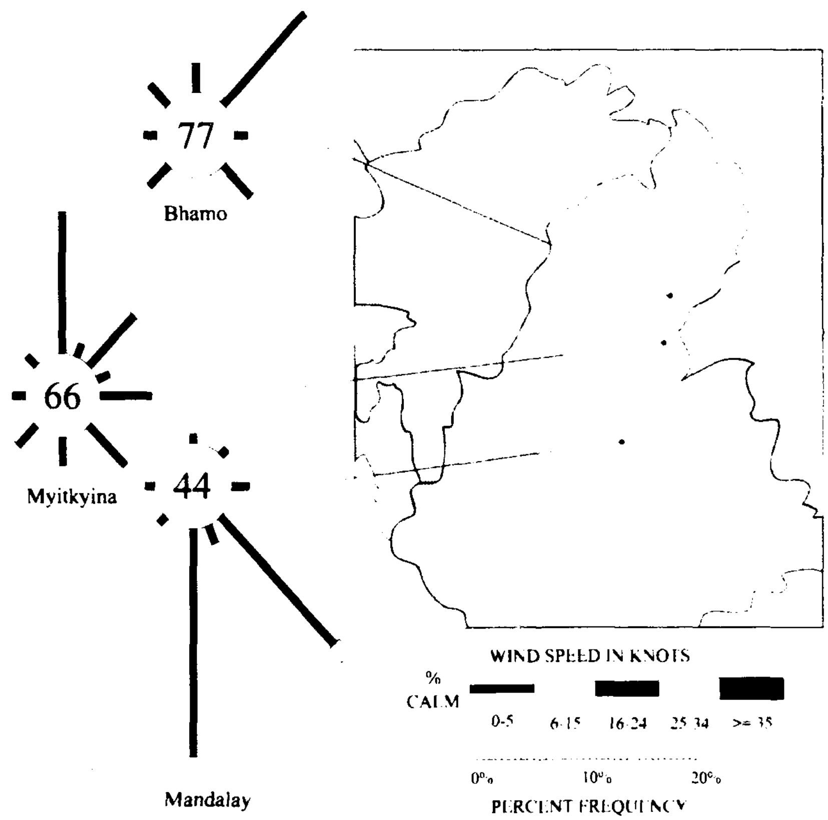


Figure 3-28. October Surface Wind Roses. The figure shows prevailing wind direction and range of speeds based on percent of frequency and location.

Upper-Level Winds. By September, the easterlies that prevailed over Myanmar for the summer are beginning to shift southward. Winds over central Myanmar are variable in direction up to 30,000 feet (9,150 meters). Steady easterlies occur at and above that level at 35-45 knots. The westerlies associated with the jet stream do not become established south of the Himalayas until October when they dominate winds above 20,000 feet (6,100 meters). Speeds range between 15 and 35 knots past 45,000 feet (13,700 meters). Below 20,000 feet (6,100 meters), winds remain variable at 10-15 knots. Figure 3-29 shows upper-air wind roses for representative locations.

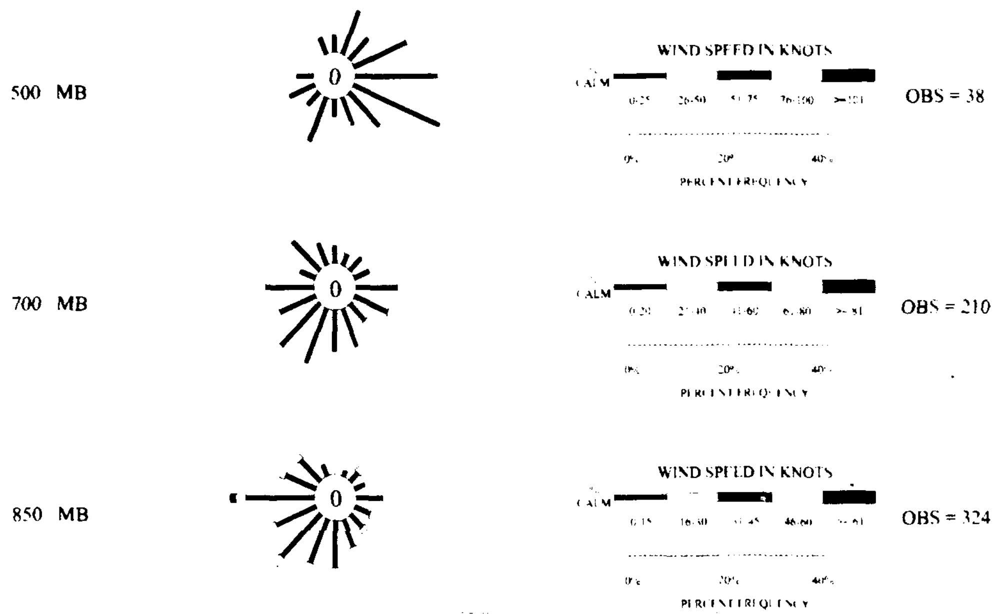


Figure 3-29. October Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 and 500 mb at Mandalay, Myanmar. Note: Each wind rose has a tailored legend.

Precipitation. Figure 3-30 shows mean precipitation totals for representative months of the season.

Central Myanmar. Mean rain and drizzle amounts decrease from just under 6 inches (152 mm) in September to 5 inches (127 mm) in October. Most of the sustained high precipitation totals result in increased convective activity. Totals have reached almost 14 inches (355 mm) in September, mostly associated with tropical disturbances.

Northern Myanmar. As the transition season progresses, mean precipitation in deep valleys decreases from 9 to 10 inches (229-254 mm) in September to between 4 and 6 inches (102-152 mm) in October. Terrain above 12,000 feet (3,660 meters) has snow after early October. Exact precipitation amounts over higher terrain are unknown; however, monthly amounts of 24 inches (609 mm) in September decreasing to 7-10 inches (178-254 mm) in October are probable.

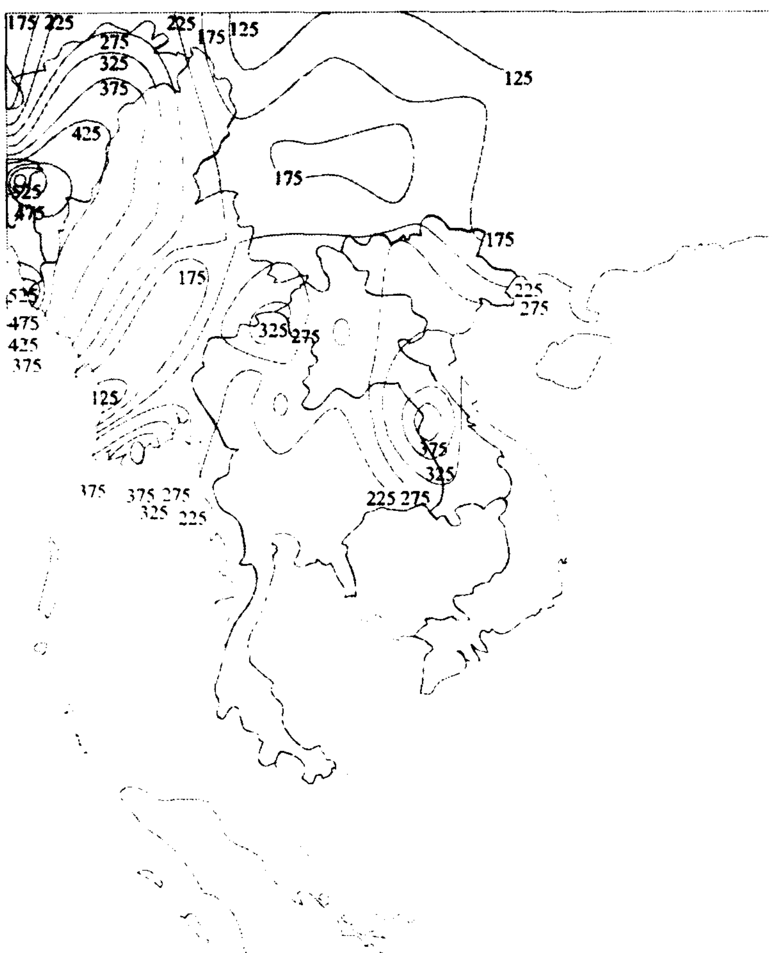


Figure 3-30. October Mean Precipitation (mm). The contours shows mean precipitation totals for central southeast Asia during the post-monsoon season.

Thunderstorms. Figure 3-31 shows mean number of precipitation and thunderstorm days.

Central Myanmar. Thunderstorms, although still not common, reach a secondary maximum in September. Frequency distributions show 1500-1700L as the favored occurrence time. Tops reach 40,000 to 50,000 feet (12.2 to 15.3 km); isolated tops may reach 55,000 feet (16.7 km).

Northern Myanmar. Thunderstorms have their secondary maximum during September over valley stations; occurrences decrease rapidly during October. Reports from USAAF pilots flying the "Hump" in World War II and subsequent commercial airline reports indicate that thunderstorms associated with upper-level troughs are common over ridges. Thunderstorm lines develop over higher ridges that are oriented perpendicular to the mean upper-air flow. Once formed, these lines move eastward with the trough. Thunderstorm tops range from 40,000 to 50,000 feet (12.2 to 15.2 km).

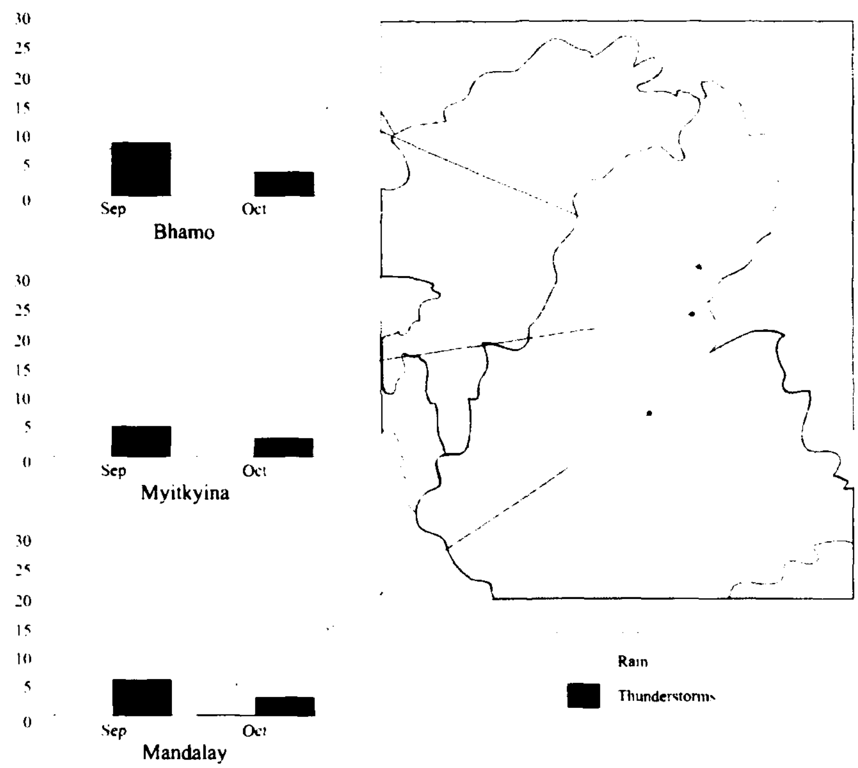


Figure 3-31. Post-Monsoon Precipitation and Thunderstorm Days. The graphs show the number of days with rain and thunderstorms based on monthly average occurrences at scattered locations in central southeast Asia.

Temperatures. Figures 3-31 and 3-32 show mean maximum and minimum temperatures, respectively.

Central Myanmar. Maximums decrease from 31°C in September to 30°C in October. Minimums average 24° to 25°C. Extreme maximums have reached 40°C in September. Extreme minimums range from 20°C in September to 19°C in October.

Northern Myanmar. In deep valleys below 1,000 feet (310 meters), maximums range from 28°C in September to 27°C in October. Minimums vary between 24° to 23°C. Extreme maximums have reached 37°C in September. Extreme minimums have dropped to 15°C at Myitkyina; minimums drop below freezing on the highest peaks. The assumed lapse rate for use in these mountains is 2°C per thousand feet.

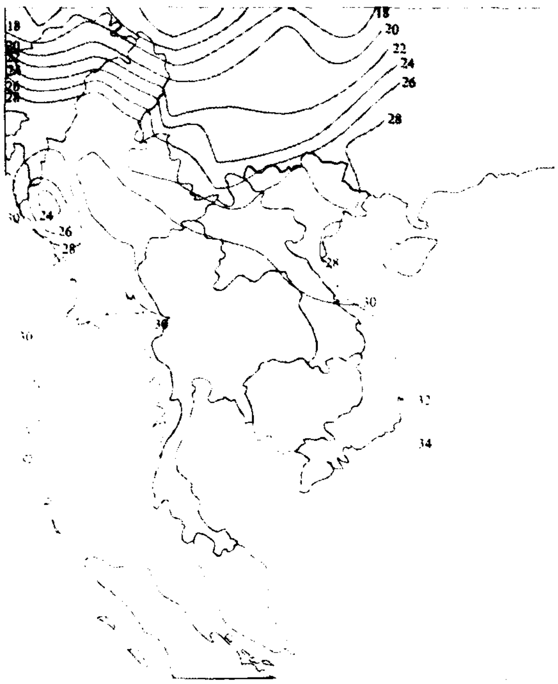


Figure 3-32. October Mean Maximum Temperatures (°C). The isopleths represent the average of all high temperatures during the post-monsoon season.

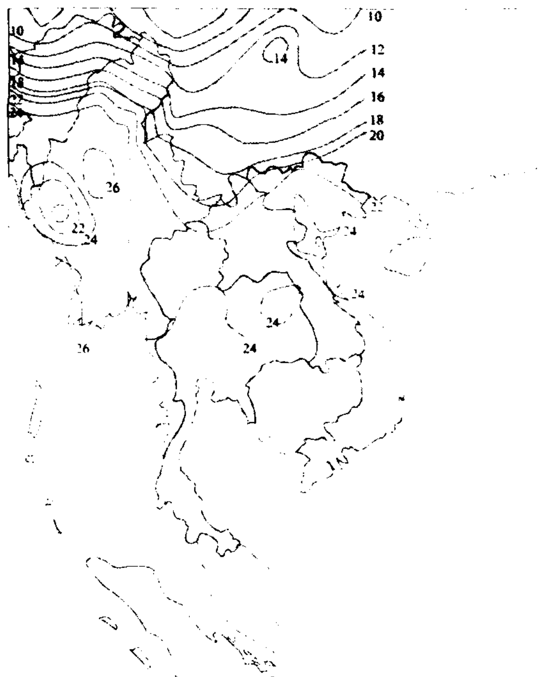


Figure 3-33. October Mean Minimum Temperatures (°C). The isopleths represent the average of all low temperatures during the post-monsoon season.

Other Hazards.

Central Myanmar. This season has an occasional tropical disturbance or easterly wave just before the monsoon trough moves southward in southern Myanmar. Frequencies are low, less than one disturbance per month in October. Rarely do these systems reach tropical storm strength. Conditions in them are those typical of the southwest monsoon. Light to occasionally moderate turbulence occurs over the mountains; light to occasionally moderate mixed icing occurs above 16,000 feet (4.9 km). Visibilities and ceilings are reduced to near zero in torrential rains near the center of these waves. Severe mixed icing and turbulence occur in/near thunderstorms. Icing is confined to heights above 16,000 feet (4.9 km); turbulence occurs at any level. Turbulence hazards are increased by the combination of thunderstorm downdrafts and mountainous terrain. Moderate mixed icing also occurs above 15,000 feet MSL (4.6 km) in the layered clouds of the southwest monsoon. Moderate turbulence occurs over the Chin Hills-Arakan Mountains region in southwesterly flow.

Northern Myanmar. Light to occasionally moderate turbulence occurs over ridges below 3,000 feet (1,500 meters). Moderate to occasionally severe turbulence occurs over ridges above 3,000 feet (1,500 meters) with fresh outbreaks of northeast monsoon air. Moderate to severe turbulence occurs in the proximity of ridges above 8,000 feet (2,440 meters) in and near upper troughs. Mountains waves are common over the mountains along the Myanmar-India and Myanmar-China borders after late September. Moderate to severe mixed icing is found in layered clouds between 12,000 feet (3,660 meters) and 20,000 feet (6.1 km) associated with troughs. Light to moderate mixed icing is found in orographic clouds between these elevations. The usual severe mixed icing and severe turbulence are associated with thunderstorms.

Trafficability. Soils in this area vary from mixed fine- and coarse-grained in the north to coarse-grained in the south. The coarse-grained soils of the south are less affected by wet conditions and exhibit good to fair trafficability in most instances. In the northern areas of this subregion where mixed soils are present, the fine-grained materials reduce the stability of the coarse-grained materials during the wet season resulting in fair to poor trafficability. The more rugged topography of the north also contributes to a decrease in trafficability.

Chapter 4

NORTHERN VIETNAM

This chapter describes the geography, major climatic controls, special climatic features, and general weather (by season) for northern Vietnam, as shown below.

Northern Vietnam

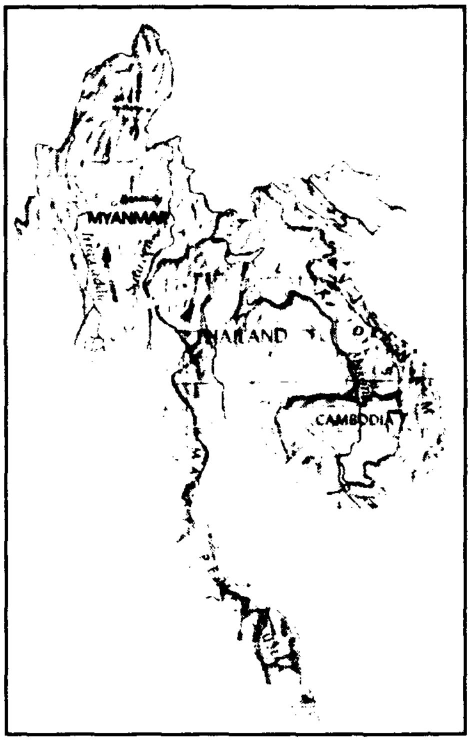


Figure 4-1. Topography. This map shows major place names, rivers, and terrain features.

Boundaries. Northern Vietnam's southern boundary lies south of the Song Ca River, in the area of Dong Hoi, and follows an east-west line into the mountains to the Laos border. Laos and China define the western and northern borders of northern Vietnam. The Gulf of Tonkin is the eastern boundary.

Topography. Rugged, mountainous terrain covers much of Northern Vietnam, especially in the northwest areas (see Figure 4-1). They are part of the southeastern extensions of the Himalayan Range and the Fan Si Pan Mountains. The northwestern and western mountains rise to more than 9,000 feet (3,000 meters). Mount Fan Si Pan (22° N, 104° E) tops 10,000 feet or 3,100 meters. Heights in the northern mountains average between 5,000 and 7,000 feet (1,500 to 2,100 meters). All the mountain ranges slope sharply down to the floor of the Red River valley, the major river system of northern Vietnam. Coastal plains at low elevations line the eastern part of the zone. These plains extend to the feet of mountains and have many rivers draining from the mountains running through them.

The zone's eastern sector contains the vast Red River delta and its accompanying lowlands. Hanoi (21° N, 105° E) is situated slightly northwest of the center of this broad lowland region, where elevations reach only slightly above sea level. Seventy kilometers north-northwest of Hanoi lies a small northwest-southeast oriented ridge extending to 5,200 feet (1,600 meters). Northeast and southwest of the Red River delta, elevations rise to more than 5,000 and 6,100 feet (1,500 and 1,880 meters), respectively. Not only are elevations higher near the Laotian border than the Chinese border, but heights continue to rise toward the southwest. Toward the northeast, elevations decrease beyond the Vietnam-China border.

Rivers and Drainage Systems. The Red River, 130 miles (210 km) long, begins in China and flows northwest-southeast through northern Vietnam along a deep, narrow gorge before broadening into a vast delta and emptying into the Gulf of Tonkin. At the Gulf, the Red River valley—the economic heart of northern Vietnam—is about 75 miles (120 km) wide. Like most rivers in Vietnam, the Red River is contained by dikes and is prone to flooding from May through October. The large quantities of iron oxide in the water give the river its red hue. The other primary rivers in northern Vietnam—Chay, Lo, Gam, Cau, Black Da, Ky Cung, and Ba Che—generally flow northwest-southeast and either flow into the Red River or empty directly into the Gulf of Tonkin. Northern Vietnam has no large lakes; the Gulf of Tonkin is the main body of water in the area. The Gulf of Tonkin is the northwest arm of the South China Sea.

Vegetation. Northern Vietnam's vegetation is rich and diverse because of the area's great range of topography and soils and the varying effects of human habitation. Deciduous trees and evergreens abound in northern Vietnam's forests. There are more than 1,500 species of woody plants in Vietnam. There are also numerous species of woody vines and herbaceous plants. In most areas the forests are mixed, containing a large number of species within a small area. Two- and three-needled pines are generally found in the uplands, and dense mangrove forests are plentiful around coastal swamps and the Red River delta's tributaries. Brushwood, bamboo, weeds, and tall grasses invade clear cut forest and grow around settlements and along arterial highways and railroads.

Northern Vietnam also contains barren lands of sand dunes with eucalyptus and small, thorny deciduous trees and flowering plants. Colon grass is commonly found in the open forests, and grass savannas occupy large areas formerly covered by forests.

Asiatic High. Also known as the Siberian high. The northeast monsoon (October-March) brings air from the large high-pressure cell over Siberia and Mongolia to northern Vietnam. This polar continental air is originally very cold, dry, and stable; however, by the time it reaches northern Vietnam, the air mass has been thoroughly modified. It is a shallow air mass. Over southern China, its thickness rarely exceeds 10,000 feet (3,100 meters). Occasionally, a surge of the northeast monsoon brings this polar continental air to northern Vietnam via a land route. In this case, the air mass is far less modified; consequently, temperatures drop.

North Pacific High. The slow weakening of the high-pressure cell over continental Asia toward the end of the northeast monsoon (February/March), and the constant invasions of polar air lead to a general decrease in the velocity of the northeast monsoon. As the importance of the polar air mass diminishes, the easterly trade wind air from the Pacific Ocean gradually takes over. During April and May, the transition zone between the retreating northeast monsoon and the slowly advancing southwest monsoon moves over Southeast Asia from south to north. The continental high-pressure area over Siberia and Mongolia disappears, and the northeast monsoon consists almost entirely of very low-speed extended trade winds from the North Pacific Ocean.

Australian High and Asiatic (Siberian) Low. The southwest monsoon flow results from the dynamic balance between the semipermanent highs over Australia and the Indian Ocean and the semipermanent low over Asia. The air originating over Australia is warm, stable, and very dry, but it is rapidly modified as it passes over the equatorial waters. By the time this air merges over Sumatra and Malaya with flow from the Indian Ocean, it is very moist and unstable in the lower layers. The Asiatic low is a semipermanent thermal low-pressure system that sets up over continental Asia. Strong confluent flow into the low develops, and that flow is partly responsible for the northward shift of the monsoon front. The southwest monsoon prevails from April to September, but it is strongest in July and August when the Asiatic low reaches maximum development. Despite this season's name, flow over northern Vietnam is generally southeasterly, as the Asiatic low redirects the flow from the Australian high.

General. Although northern Vietnam is on the northern edge of the tropical world, monsoons still play the most significant role in this zone's weather. The northeast monsoon, which is the colder and drier of the two seasons, actually has the worse aviation weather. There is considerably less rain, but the fine drizzle that does fall can make the weather gray and gloomy for days and weeks at a time. The northeast monsoon lasts from October to March. Aviation weather is better during the southwest monsoon season. Although there is more overall cloudiness and much more rainfall, visibility is consistently higher and cloud bases are generally higher. The southwest monsoon lasts from April to September. There is no real transition interval this far north; the monsoon change-over occurs quickly. Northern Vietnam, like most regions on the northern edge of the tropical zone, stays cloudy most of the time. Sky cover is broken to overcast 50-85 percent of the time, year-round throughout the region. Clear skies are rare.

Polar Front Disturbances. The mean polar front position at sea level during January is around 25° N, but it frequently moves over large distances and can be as far south as 10° N. At higher levels, the front is farther south. This is due to the Himalaya Mountains, which cause the air to tilt forward instead of backwards. At about 10,000 feet (3,100 meters), its mean position is around 15°-20° N, oriented southwest to northeast over southeast Asia. This is roughly the same position as it is at just 2,000 feet (600 meters). Disturbances that follow tracks near the polar front are responsible for most of the widespread precipitation in northern Vietnam during the northeast monsoon. During the southwest monsoon season, the polar front vanishes in the mountains north of northern Vietnam and associated disturbances disappear with it.

Crachin. Crachin conditions occur in periods that normally last 2 to 5 days but can stretch into 20 days or more. This condition is characterized by fog or heavily overcast skies and light drizzle; only a small amount of measurable precipitation occurs. The local population calls this "rain dust" or "flying rain" because of the extreme fineness of the droplets. Rain dust is most common in February and March. The worst and most persistent crachin is formed by the cooling of warm, moist air as it moves over cooler coastal waters and is advected ashore. This follows normal flow around the base of the Asiatic high. Although the air starts out continental, its long trajectory gives it plenty of time to modify. These conditions also occur, if less persistently, when a shallow depression on a weak front (not the polar front) stalls out over the Gulf of Tonkin. These weak fronts develop over northern Vietnam and move into the Gulf of Tonkin and the South China Sea as a result of cold surges from the Siberian high. The main crachin season is from the end of January to April.

Jet Streams. In the northwest monsoon season, a ribbon of westerly winds associated with a branch of the subtropical jet extends south of the Himalayan Massif and reach northern Vietnam. During most of the southwest monsoon, an easterly jet is dominant. Its position fluctuates widely between 10° and 25° N. There is a correlation between the position of this easterly jet stream and disturbances at lower levels, which often bring heavy precipitation to the area.

Tropical Cyclones. Tropical cyclones mainly affect northern Vietnam from June through October; most occur in August and September. The storms primarily track southeast-northwest over Hainan Island and the Gulf of Tonkin and then into northern Vietnam. The greatest destruction associated with tropical cyclones occurs on the coast and is caused by wind, flooding from the heavy rain, abnormally high tides, and heavy seas. Widespread torrential rainfall floods river channels, lowlands, and delta regions and may wash out roads, communication lines, and airfields. Even in protected interior regions, the remnants of dissipating cyclones sometimes cause widespread flooding. When a tropical cyclone approaches northern Vietnam but does not make landfall, it interrupts the monsoonal flow. This generally decreases cloudiness along the coasts. In the mountains, cloudiness increases and showers and thunderstorms occur frequently. Although the majority of tropical cyclones occur from June through October, it is possible for them to occur any time of the year.

Typhoons and tropical storms have similar characteristics and vary only in degree of severity and areal coverage. Typical wind speeds in typhoons affecting this area are about 45 knots at 50 miles (80 km) from the center and 65 knots or more at 30 miles (48 km) from the center; in tropical storms, winds cover a smaller radius and are somewhat weaker. Coasts are most susceptible to typhoon damage, where torrential downpours can drop up to 16 inches (406 mm) of rain a day and winds can gust up to 70 knots. Typhoons affect the area between June and October, but most often in September. During one 20-year period, northern Vietnam experienced nine typhoons in September and six in October.

Extratropical Cyclones. These eastward-moving lows usually affect the northern part of the area from January to March. These lows ride the westerly jet wind ribbon across India and into northern Indochina. Like tropical cyclones, these storms interrupt the monsoonal flow. Coastal areas experience clearing with the offshore flow followed by increasing cloudiness and rain over higher terrain after the low moves into the Gulf of Tonkin.

Topographical Effects. The Annam Mountains of central Vietnam exert their own influence on the general surface flow. The Annam Mountains are perpendicular to the southwesterly flow, producing a lee side effect on northeastern mountain slopes. This effect enhances the redirection of the general surface flow toward the northwest over northern Vietnam.

General Weather. During October, the cool northeast monsoon rapidly replaces the warm southwest monsoon. November through March is generally referred to as winter, when extreme temperatures can reach 0°C. Northern Vietnam's coasts and lowlands frequently experience poor visibility and low cloudiness during this season. Precipitation is at a minimum in the uplands but falls as much as 25 days a month along the coast. Crachin produces long spells of poor conditions. Despite this, there is little accumulation.

As the low-level northeast monsoon air moves across the relatively cooler waters of the Kuroshio Counter Current, widespread coastal stratiform cloudiness and drizzle may develop. The general wind pattern extends to heights of about 5,000 feet (1,500 meters) or less; therefore, higher terrain usually experiences less cloudiness and better visibility than coastal areas and river valleys. Occasionally, a surge of the northeast monsoon brings colder air to northern Vietnam via a land route. These surges are rare but do cause sharp temperature drops.

Although contrary to some tropical meteorology concepts, frontal activity occurs in the Gulf of Tonkin and the South China Sea where weak fronts are relatively common during the northeast monsoon. The generally east-west oriented fronts are triggered by surges of polar air from the Siberian high. The air moves southward over the area. In advance of the fronts, clouds are convective and produce showers. Behind the fronts, clouds are multilayered with intermittent light rain. These conditions are conducive to the development of crachin weather along the northeastern coast as microscale lows stall out along these weak fronts. The rest of northern Vietnam is unaffected by these fronts.

The official tropical cyclone season lasts from June through November. Tropical cyclones can o any time of the year, but after October, the uncommon. Late season tracks bring storms ac Hainan Island and into the Gulf of Tonkin. The storms impact the coastal areas the most, bringing destructive winds and high tides along with heavy rain. Inland locations are less disturbed but still experience increased cloudiness, heavy convection over mountains, and heavy rain in association with the convection.

Sky Cover. Crachin causes the lowest ceilings, poorest visibility, and most prolonged cloudy conditions along northern Vietnam's coasts. The associated stratus decks frequently have bases below 500 feet (150 meters) and have an average thickness of 3,000 to 5,000 feet (900-1,500 meters). Comparatively dry air dominates inland, limiting low cloudiness conditions to stratocumulus at 2,000 feet (609 meters) or better. Above the level of the monsoon winds (5,000 feet (1,500 meters) more or less), conditions improve. High elevation locations often have broken to overcast cloud tops below their elevation with scattered clouds above. Occasional early morning stratus decks may form, especially in steep-sided river valleys, but the decks generally dissipate by late morning. Scattered cumulus may develop with daytime heating; bases are between 1,500 to 3,000 feet (450-900 meters) MSL. Extensive cloud cover is the norm for northern Vietnam. Broken to overcast conditions (low- and middle-cloud) exist 60-85 percent of the time throughout this region during the northeast monsoon (see Figure 4-2). Completely clear skies occur an average of less than 2 percent of the time.

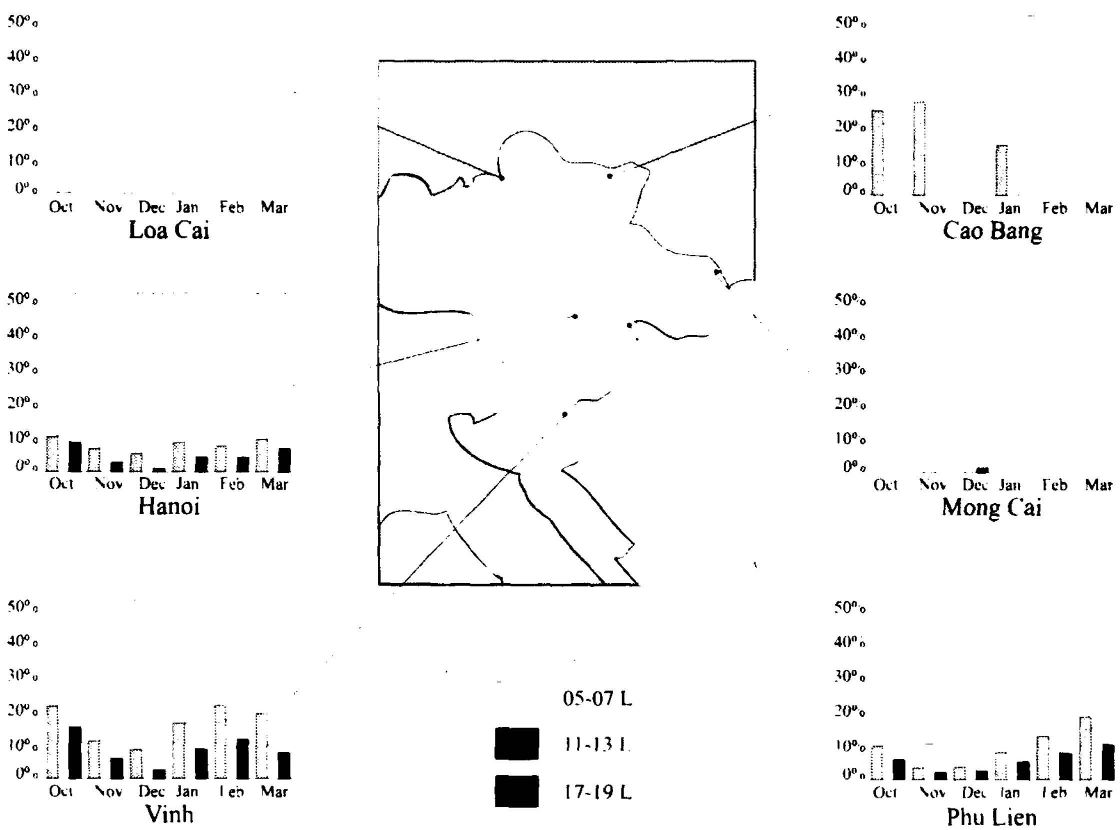


Figure 4-2. Northeast Monsoon Ceilings below 3,000 feet. The graphs show a monthly breakdown of the percentage of ceilings below 3,000 feet based on location and diurnal influences.

Visibility. Crachin causes prolonged visibility restrictions along the coast. During crachin events, fog and extremely fine drizzle reduces average visibility to less than 3 miles (4,800 meters). The poorest visibility occurs between 0400L and 0800L; however, it generally improves to 4 to 6 miles (6,000-9,000 meters) during the day. Inland visibility of 1/2 to 2 miles (800-3,200 meters) can continue throughout the day with little improvement. Aside from crachin conditions, visibility below 3 miles (4,800 meters) is common along the coast during the morning, but it usually improves to above 6 miles (9,000 meters) by late morning (see Figure 4-3). Areas above the 5,000-foot (1,500-meter) elevation have fewer problems with low visibility. With the exception of early morning fog, visibility remains good. Haze restricts visibility all over northern Vietnam, but conditions usually remain above 5 miles (9,000 meters).

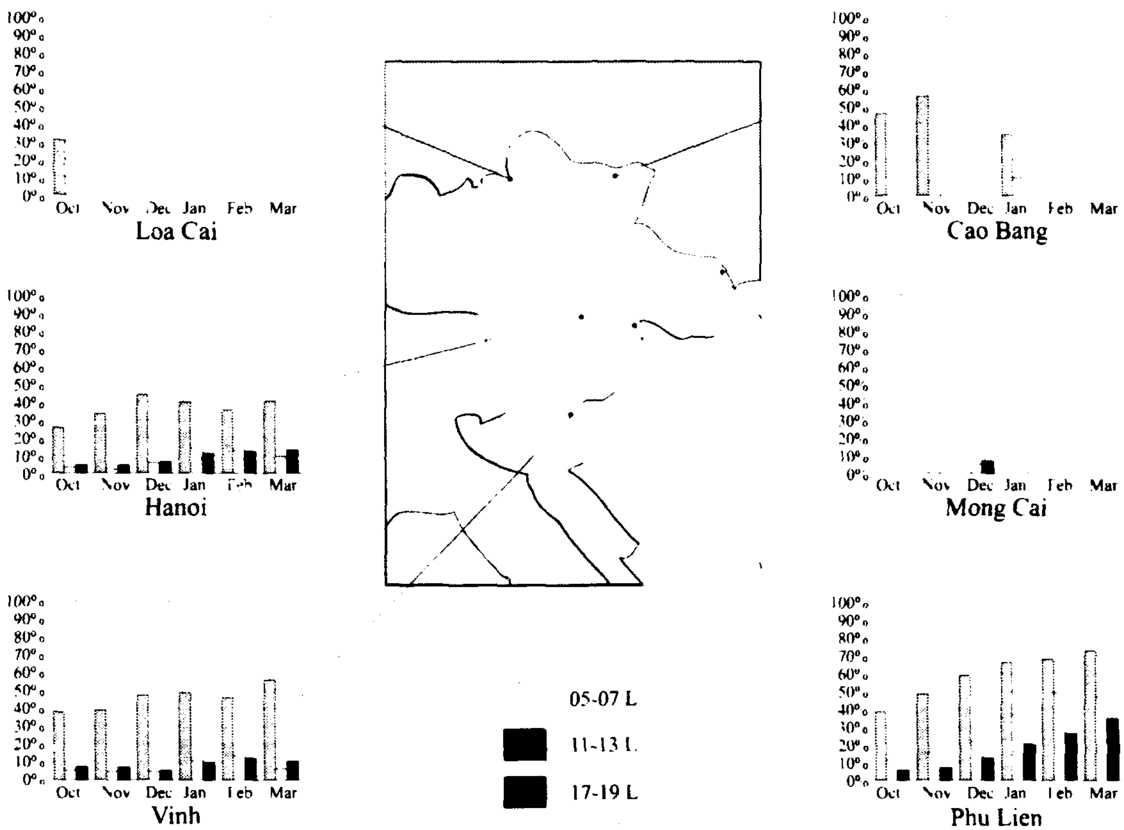


Figure 4-3. Northeast Monsoon Visibility below 3 Miles (4,800 Meters). The graphs show a monthly breakdown of the percentage of visibility below 4,800 meters based on location and diurnal influences.

Winds. Like the rest of the tropical zone, northern Vietnam is in an area of relatively weak flow. Outside of thunderstorm gusts and typhoon winds, top speeds recorded throughout the region remain in the range of 20 to 25 knots and calm winds prevail more often than not. Consequently, local effects seriously influence the surface wind regime. Hanoi, for example, experiences northwesterly winds channeled through the Red River valley and land/sea breezes associated with pressure gradients between the land and the Gulf of Tonkin. The sea breeze near the coastal city of Phu Lien is especially noticeable at 1900L, when southeasterly flow is evident in both October and January. Even at Hanoi, 56 miles (90 km) inland, winds from the southeast prevail over the monsoon flow at that hour. Overall flow for the season is from the northeast, but all of northern Vietnam is under especially light and variable conditions during October and January (see Figure 4-4). The lack of a distinct prevailing direction is especially evident in October before the northeast monsoon becomes well-established. Average surface wind speeds are 15 knots or less, and calm winds are reported frequently. Mountain winds are generally light unless channeled through passes; nighttime drainage winds are also light. Despite these generally calm conditions, tropical disturbances affecting northern Vietnam early in the northeast monsoon can bring much higher wind speeds. Hanoi has seen storm-related wind gusts of 64 knots as late as March.

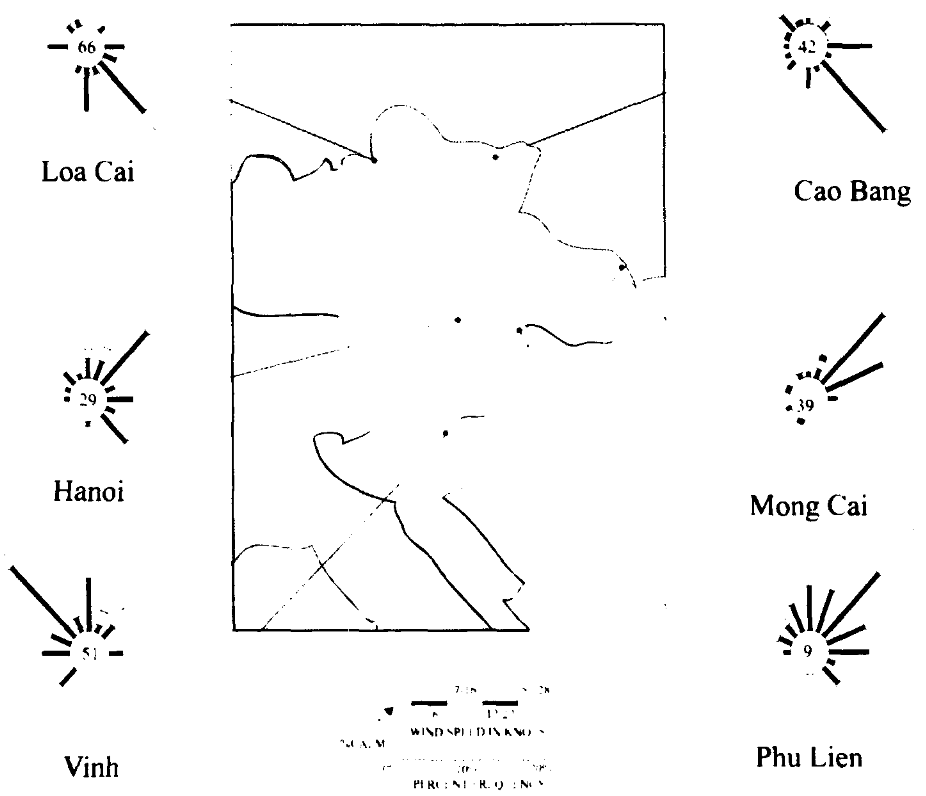


Figure 4-4. January Surface Wind Roses. The wind roses show surface wind speed, direction, and frequency of occurrence for representative locations within northern Vietnam.

Upper-Level Winds. The northeast monsoon air mass, usually too shallow to traverse the mountains, generally does not reach above 5,000 feet (1,500 meters). Confluence of the air streams north and south of the Himalayan-Tibetan Massif produces a strong westerly jet just north of northern Vietnam with speeds of 60-70 knots above 30,000 feet (9,100 meters). Northern Vietnam itself lies in the transition zone between the westerly jets and the tropical easterlies. For this reason, winds over the region remain relatively light and variable (10-15 knots even at high altitudes) throughout the year (see Figure 4-5). By the end of the season, the jet shifts north and tropical easterlies move closer but don't quite arrive over northern Vietnam.

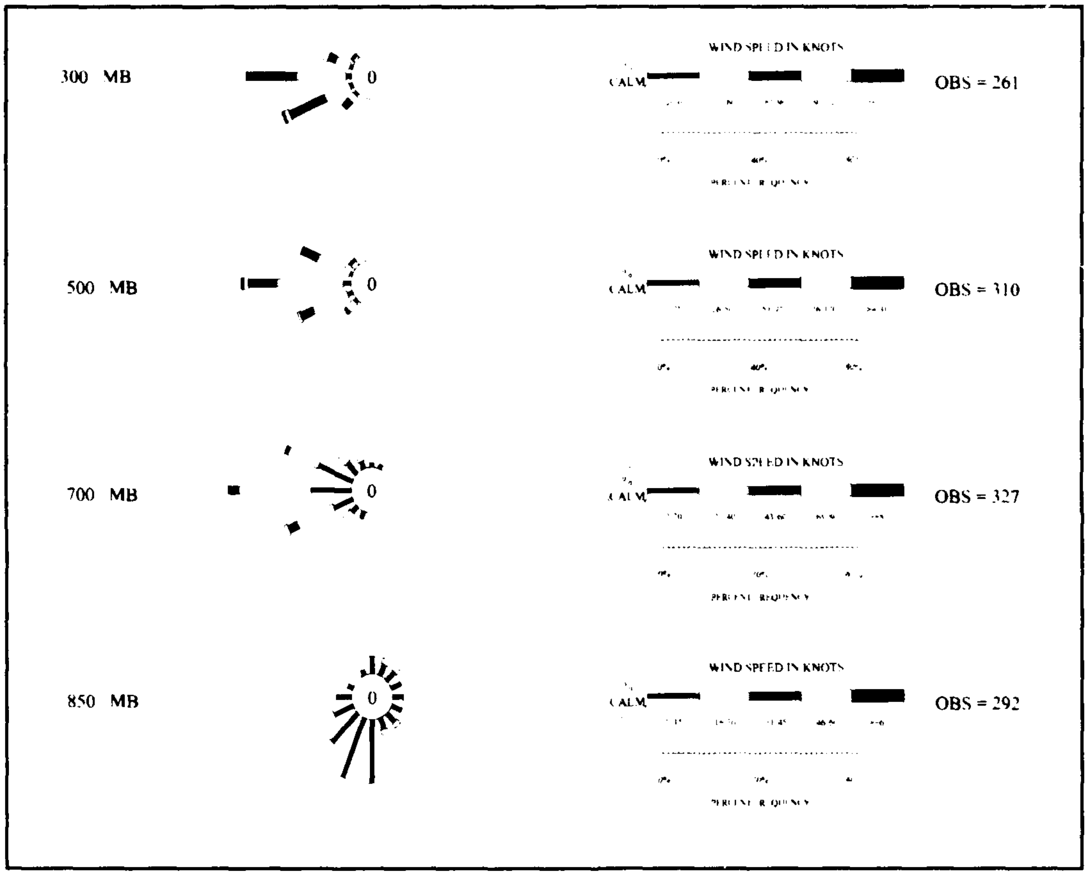


Figure 4-5. January Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 and 300 mb at Hanoi, Vietnam. Note: Each wind rose has a tailored legend.

Precipitation. Embedded showers are reported from the September transition through December, but strong subsidence from the Asiatic (Siberian) high brings northern Vietnam's driest conditions this time of year. Nevertheless, the monthly number of days with precipitation can vary from zero in the mountains to more than 25 days along the coast. This precipitation, mostly stratiform, rarely amounts to more than .5 inch (13 mm) a day (see Figure 4-6). Along east facing slopes near the coast, however, more than 4.5 inches (110 mm) has fallen in 24 hours. Late in the season, crachin brings the greatest ber of rain days to the area. Mist or light drizzle occur more than 25 days a month along the st and the Red River valley. Despite this, rainfall amounts are lower than might be expected. The widespread rainfall from polar front disturbances is locally increased by orographic lifting. Do not overestimate the overall importance of orographic lifting, because there is no doubt that the main source of the precipitation are the disturbances. This is demonstrated by the intermittent and irregular character of the rainfall, by the occurrence of rain in the predominantly flat Red River basin, and by the fact there is no close correlation between the strength of the monsoon winds and the amounts of rainfall received. Occasionally, heavy precipitation may also occur as a result of typhoons entering the area from the Gulf of Tonkin, but these are extremely rare in the months between October and June.

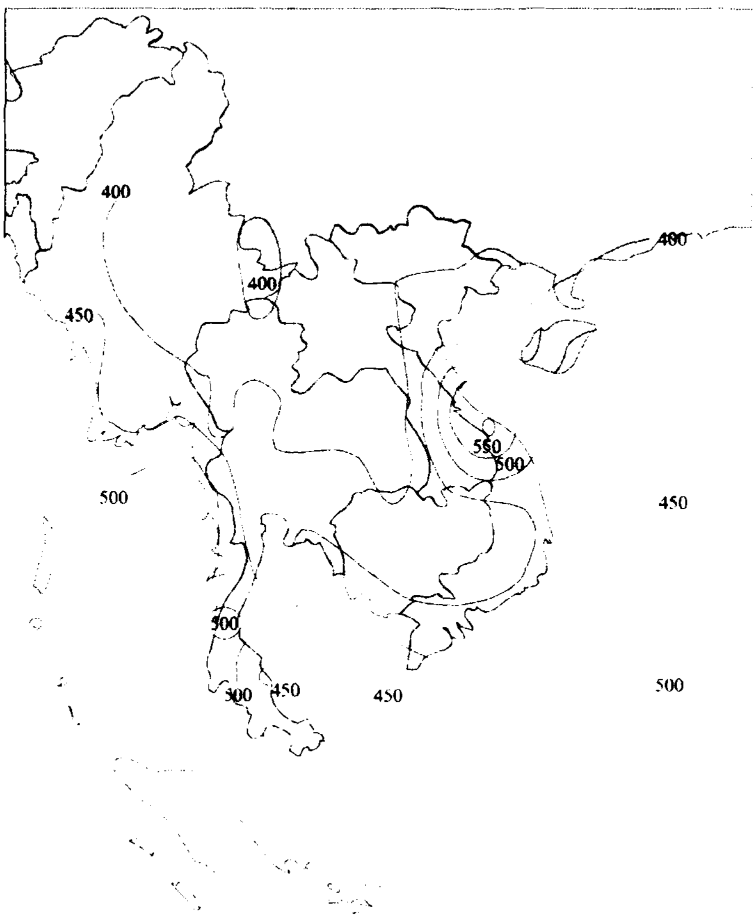


Figure 4-6. January Mean Precipitation (mm). The contours show the light precipitation amounts that occur during a representative month of the northeast monsoon.

Thunderstorms. Thunderstorm activity is at a minimum during the northeast monsoon. Many locations throughout northern Vietnam report no thunderstorm activity from November through February; October and March average only 1 or 2 thunderstorm days (see Figure 4-7). Thunderstorms occur more frequently during the transition months as upper-level subsidence decreases. The absence of a clear general circulation during the transitions leads to strong surface heating over inland areas, and the heated air is slowly removed by turbulence. Thunderstorm tops can reach 60,000 feet (18,300 meters). Bases have been reported at less than 500 feet (152 meters) while embedded in stratus, but outside of stratus, bases generally start at 1,500-3,000 feet (450-900 meters). The major thunderstorm generator during the northeast monsoon is the occasional easterly wave, which can produce thunderstorms after trough passage.

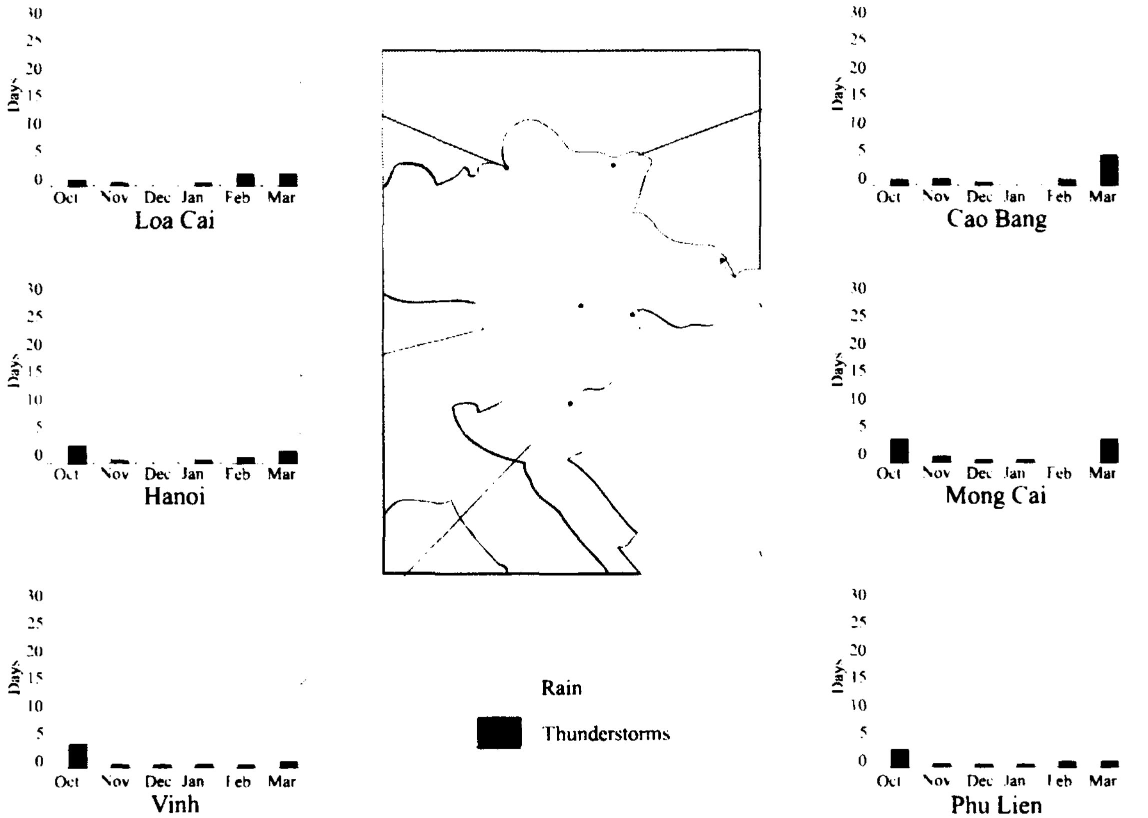


Figure 4-7. Northeast Monsoon Precipitation and Thunderstorm Days. The graphs show the number of days with rain and thunderstorms based on monthly average occurrences at scattered locations within northern Vietnam.

Temperatures. Northern Vietnam's lowest temperatures usually occur in January and February with mean highs from 16°-19°C. Mean highs in October through December and again in March are between 22°-27°C. The mean lows range down to 11°-13°C, but some stations dip to 07°-09°C. Lows in the south are generally 12°-15°C during October and November. Temperatures drop to 10°-12°C in January and February. Temperatures do not generally fall below 15°-16°C late in the season. Because of higher elevations, the mountains experience colder conditions than the lowlands. The extreme lows occur when cold air is channeled into the area from the north. The higher the elevation and the further north a location is, the greater the probability it will experience extreme low temperatures below freezing. Extreme lows range from -2°C at Chapa (in the extreme western corner) to 4°C at Vingh (south coast). Figures 4-8 and 4-9 show mean maximum and minimum temperatures, respectively.

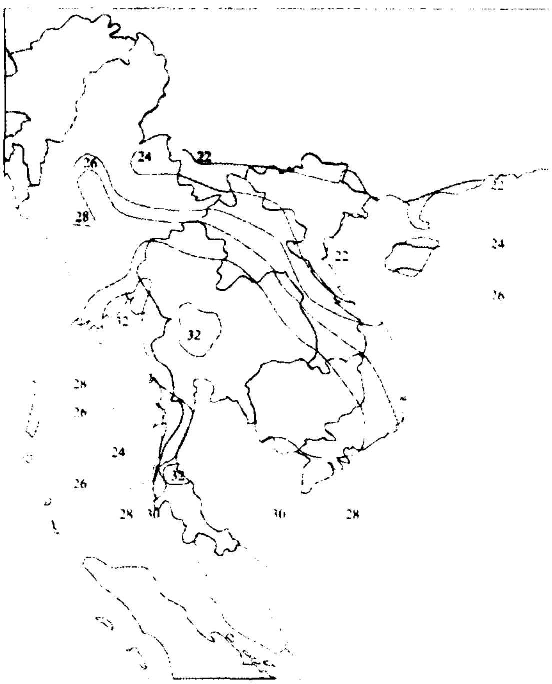


Figure 4-8. January Mean Maximum Temperatures (°C). The isopleths represent the average of all high temperatures during the dry season.

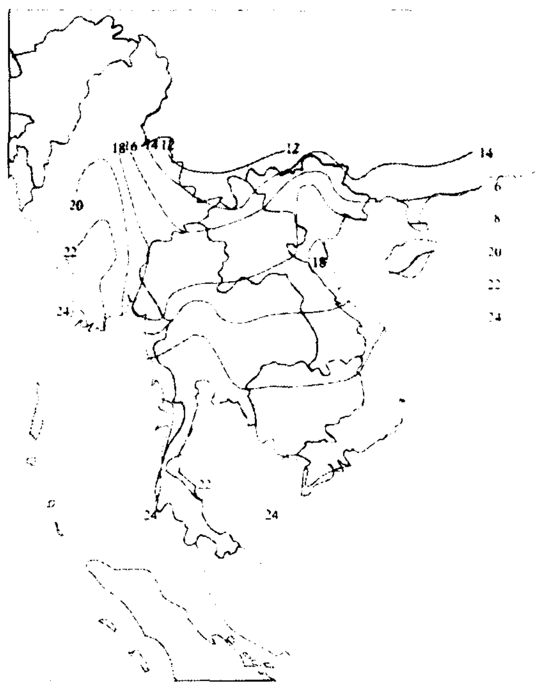


Figure 4-9. January Mean Minimum Temperatures (°C). The isopleths represent the average of all low temperatures during the dry season.

Hazards. Crachin, with very low ceilings and reduced visibility, creates an air operations hazard. Typhoons can still move into the region as late as November, bringing torrential rain and flooding. The coastal areas are most vulnerable to flooding and to storm wind damage; inland areas are better for both. Tropical disturbances have brought high winds (up to 64 knots) into the area as late as March. Thunderstorm activity is limited in winter, but can still produce icing, moderate to severe turbulence, and wind gusts to 35 knots. Hail is generally small and does not usually make it to the ground before falling.

Trafficability. Soils in this area are predominantly fine-grained silts and clays, but in the Red River delta, there are some course-grained soils beneath the silts and clays. During the dry season, conditions improve over the sodden mud. Soils dry and trafficability improves. By the end of December, vehicles can generally make good headway even over unpaved roads. The rugged topography in the far north and west always makes travel difficult. In the Red River valley, extensive diking to create canals and rice paddies necessitates using circuitous routes in the best of weather. Overall, northern Vietnam's trafficability is fair to poor; fair conditions exist in the Red River delta.

General. As the Near Equatorial Tradewind Convergence (NETWC) migrates northward in the spring, precipitation and convective cloudiness gradually increase until they reach their maximums during the southwest monsoon. Southeasterly flow over the Gulf of Tonkin adds substantial moisture to the air mass crossing the Annam Mountains. Orographic lift augments the convective process and substantial rainfall, cloudiness, and shower activity occur on the area's eastern windward slopes. Heavy and frequent precipitation, high humidity, early morning stratus, late morning and afternoon cumulus, relatively good visibility, and high temperatures characterize the southwest monsoon. Ceilings and visibility are usually adequate for air operations over northern Vietnam. Haze, fog, smoke, and rain are the principal obstructions to visibility. Frequent and heavy rainfall sometimes causes widespread flooding in the lowlands. Winds are generally light; strong winds usually only occur with thunderstorms or occasional tropical cyclones.

During April and May there is no discernible general circulation over northern Vietnam, and broad air stream boundaries dominate the area. The absence of clear, general circulation has an important consequence. Over inland areas, strong surface heating takes place. The heated air is only slowly removed by turbulence. These zones of slowly converging air masses are characterized by rising air and general instability in the lower atmosphere. Abundant cloudiness and precipitation follow. Tropical cyclone season lasts from June through November with the peak time in August and September. Most tracks that affect northern Vietnam at this time of year cross the southern end of Hainan Island and the Gulf of Tonkin to smash into the coast. Coastal locations suffer the most damage. Destructive tides and winds, heavy rain, and widespread flooding accompany these storms. Further inland, the impact is considerably less. Increased heavy convection and rain do occur, but are not much worse than normal southwest monsoon weather.

Sky Cover. The number of days with crachin conditions decreases from 2-5 in April to zero by May. During the early morning, however, stratus ceilings with bases 1,000-2,000 feet (300-600 meters) regularly occur over the mountains and the Red River region; ceilings below 1,000 feet (300 meters) also occasionally form here. Cumulus clouds with bases 2,000-3,000 feet (600-900 meters) form over most areas during the late morning and commonly produce ceilings in the afternoon (see Figure 4-10). Cumulonimbus clouds exceed 50,000 feet (15,250 meters), while altocumulus forms bases at 8,000-15,000 feet (2,400-4,600 meters). Thunderstorm-related low cloudiness usually dissipates rapidly after sunset. Cirrus clouds above 30,000 feet are also often present. Convection is very efficient because of the air mass moisture and relatively high temperatures. Orographic lifting contributes to the buildup of cloud masses on windward slopes, frequently obscuring mountain tops. Mean cloudiness ranges from 60 to 85 percent all over the region, but very low stratus ceilings do not occur nearly so often as they do during the northeast monsoon season.

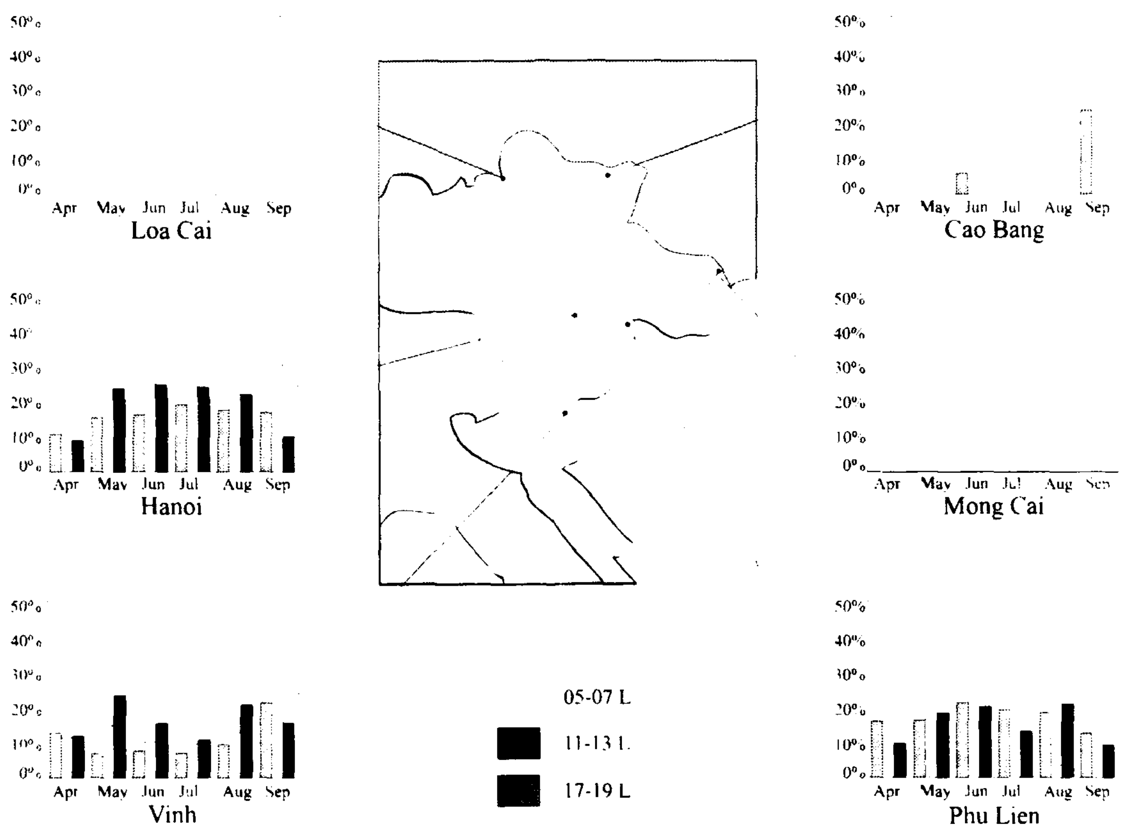


Figure 4-10. Southwest Monsoon Ceilings below 3,000 feet. The graphs show a monthly breakdown of the percentage of ceilings below 3,000 feet based on location and diurnal influences.

Visibility. Fog restricts visibility 4-6 days per month in mountain valleys; elsewhere 2 days or less are restricted (see Figure 4-11). Radiation fog is most prevalent and persistent in deep, steep-walled valleys. Fog generally forms before dawn and dissipates by 0800L, but it may form earlier and persist through the morning in deeper valleys that don't receive as much insolation as surrounding mountain slopes. Smoke and haze are frequently recorded in combination with fog. Rain showers briefly reduce visibility to less than 5 miles (8,000 meters), while thunderstorms may reduce it to less than 1 mile (1,600 meters). Although it is always cloudy, visibility under cloud cover is normally unrestricted except for periods of rain.

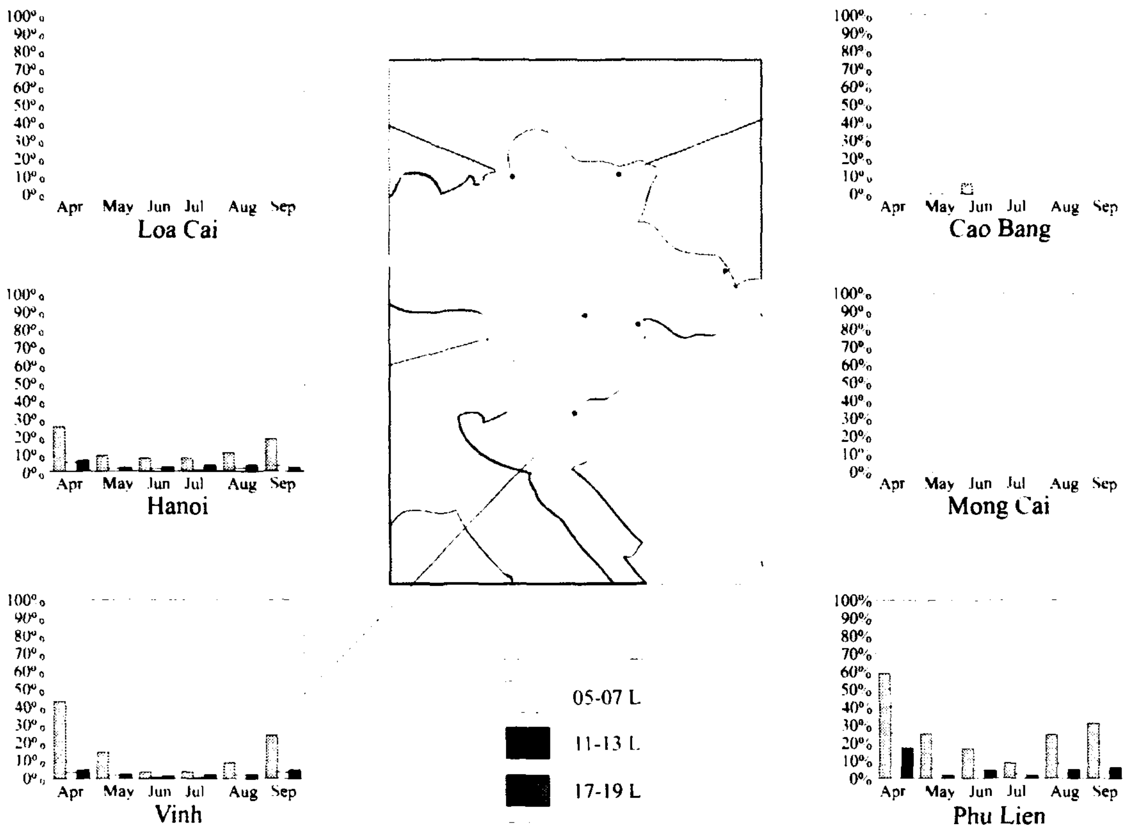


Figure 4-11. Southwest Monsoon Visibility below 3 Miles (4,800 Meters). The graphs show a monthly breakdown of the percentage of visibility below 4,800 meters based on location and diurnal influences.

Winds. Despite the general southwesterly surface flow over most of southeast Asia, northern Vietnam experiences primarily southeasterly winds early in the southwest monsoon (see Figure 4-12). This is because the Annam Mountains of central Vietnam deflect the southwesterly flow enough that it comes into northern Vietnam from the southeast. The sea breeze augmentation of this flow is especially noticeable at 12Z (19L) at Phu Lien and Hanoi even though they are both well inland. Although not as strong as the sea breeze, the effects of the land breeze are also evident at 00Z (07L). Wind flow is very weak throughout the region, and calm conditions occur at higher frequencies in the region than any other conditions. Outside of thunderstorm gusts that can top 45 knots, and typhoon winds that can exceed 70 knots along the coast, overall flow does not exceed 20-25 knots. Typhoon winds, which are quickly blunted in the mountainous terrain, are generally not significant for other than coastal areas. Local terrain, however, greatly influences wind direction and speed. In some northern mountains locations, for example, channeling produces northwesterly winds despite the southwestern monsoon. Obviously location and topography play a major role in determining both direction and strength of winds. The strongest winds usually occur along the coastal areas, but speeds are generally below 16 knots and average only 5-6 knots.

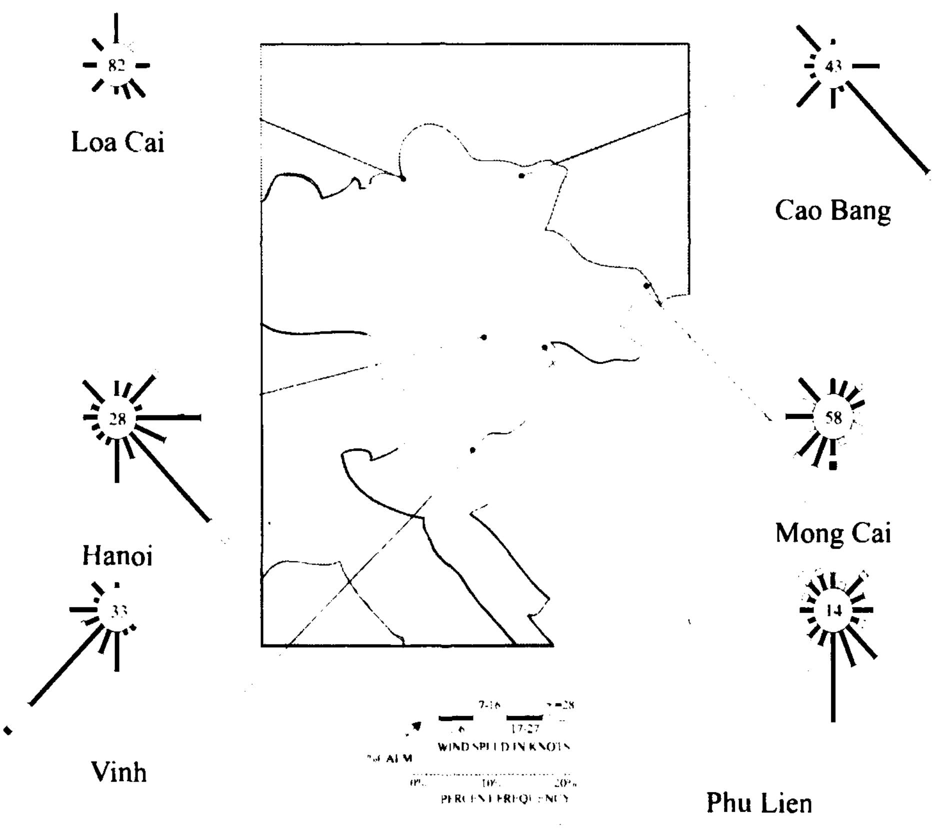


Figure 4-12. April Surface Wind Roses. The wind roses show surface wind speed, direction, and frequency of occurrence for representative locations within northern Vietnam.

Upper-Level Winds. Early in the season, westerly winds dominate from about 20,000 feet (6,100 meters) and speeds increase with height, exceeding 40 knots in the upper atmosphere (see Figure 4-12). The strongest part of the jet ribbon, which tops 75 knots over China, does not flow over northern Vietnam although it does influence the weather. Winds over the region remain light as this is the transition zone between the westerly jet and the tropical easterly jet. As the southwest monsoon progresses into June and July, overall southeasterly flow (southwesterlies deflected by the Annam Mountains) remains consistently evident through 3,000-5,000 feet (900-1500 meters). Above that level, winds become variable at 10-15 knots in the middle levels before transitioning to tropical easterly flow around 25,000 feet (7,600 meters). Easterly flow (up to 40 knots at 30,000 feet or 9,100 meters) dominates upper-level flow through the end of September when it starts to move southward, leaving variable wind directions and lower speeds behind.

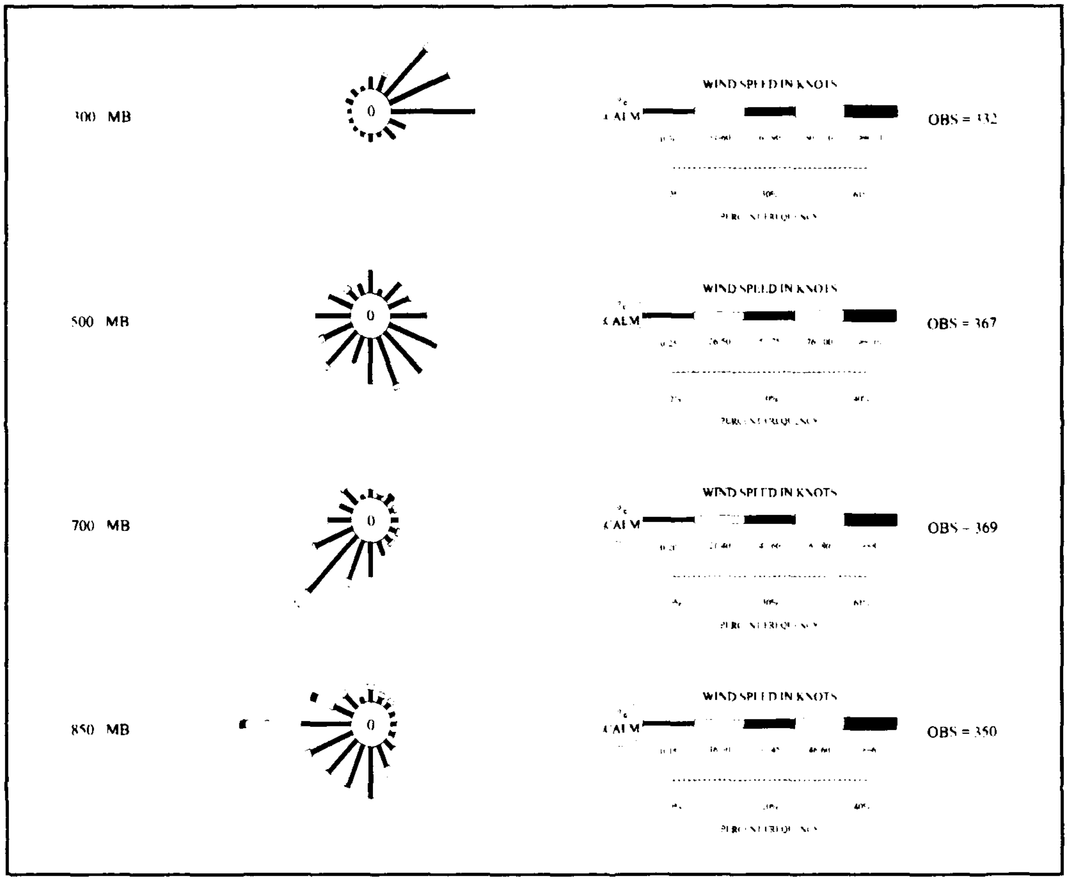


Figure 4-13. April Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 and 300 mb at Hanoi, Vietnam. Note: Each wind rose has a tailored legend.

Precipitation. Crachin conditions stop occurring before the end of April. As the southwest monsoon becomes well-established by the end of May, convective precipitation increases both because of increased orographic lifting of moisture and because of increased solar insolation. After crossing the Annam Mountains, the southwest monsoon wind flow is deflected and comes ashore in northern Vietnam from the southeast. Over the Gulf of Tonkin, this air regains much of its moisture and brings substantial rainfall to northern Vietnam. The annual rainfall maximum occurs during the southwest monsoon and is directly related to this very deep, moist air mass. Measurable precipitation falls 10-20 days a month on average. As a general rule, the further north in the region, the more rain days a location experiences (see Figure 4-14). Monthly precipitation amounts generally average 7 to 12 inches (178 to 304 mm), but many locations have reported monthly totals of up to 24 inches (610 mm). As an example, Mong Cai, on the northern coast, experiences a mean of 20, 23, and 23.4 inches (508, 584, and 594 mm) in June, July, and August, respectively. Rain showers are very intense. Most locations report maximum 24-hour rainfall amounts of 4-6 inches (102-154 mm), but Phu Lein reported an amazing 19 inches (483 mm) in a single September fall. Showers and thunderstorms are of short duration and the associated heavy rains are highly localized. Orographic lift and increased insolation provided by the northern mountains augments the convective process, enhancing cloudiness and shower activity on windward slopes. Very intense thunderstorms, which produce locally heavy rain, occur frequently over the mountains but less commonly at lower elevations.

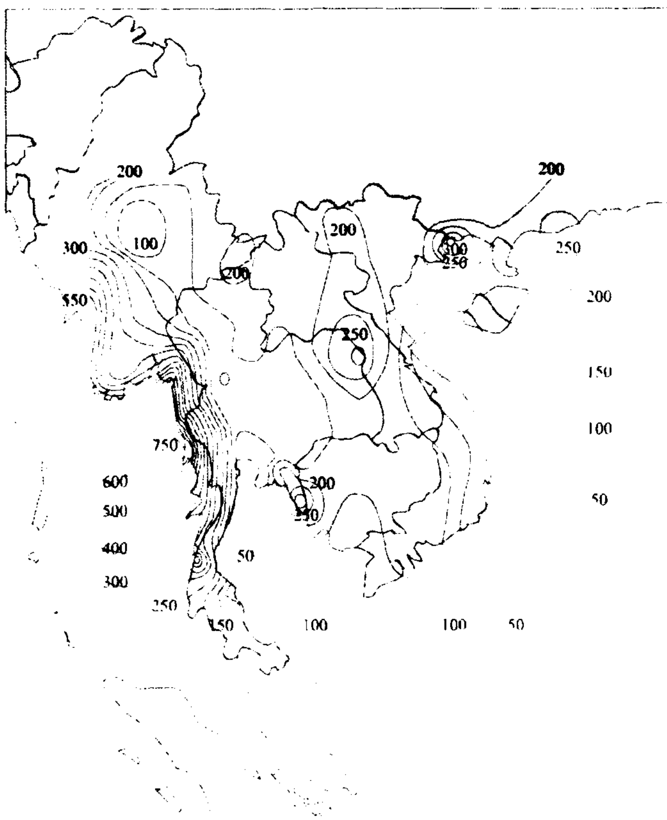


Figure 4-14. April Mean Precipitation (mm). The contours show the influence of the southwest monsoon on precipitation amounts.

Thunderstorms. Thunderstorms are a prominent feature of the southwest monsoon in northern Vietnam (see Figure 4-15). Their occurrence along the coasts is closely related to land and sea breezes, which are strongest this time of year. Tops on thunderstorms can reach 60,000 feet (18,300 meters); bases are sometimes reported at less than 1,000 feet (300 meters) for a short time. Mountain locations experience the most thunderstorms, which are tied to increased solar insolation and orographic lifting. For instance, Cao Bang (elevation 853 feet or 260 meters) gets 16 days of thunderstorms in June, 21 days in July, and 20 days in August. The location is in the north-central mountains. Maximum activity for northern Vietnam occurs in June through August with an average of 10-20 thunderstorm days a month. Thunderstorms occur at all hours but are most common during late afternoon and early evening. The afternoon maximum at 1500-1700L is only slightly greater than a secondary maximum that occurs between 0000 and 0500L. Minimum activity occurs from 0700 to 1000L.

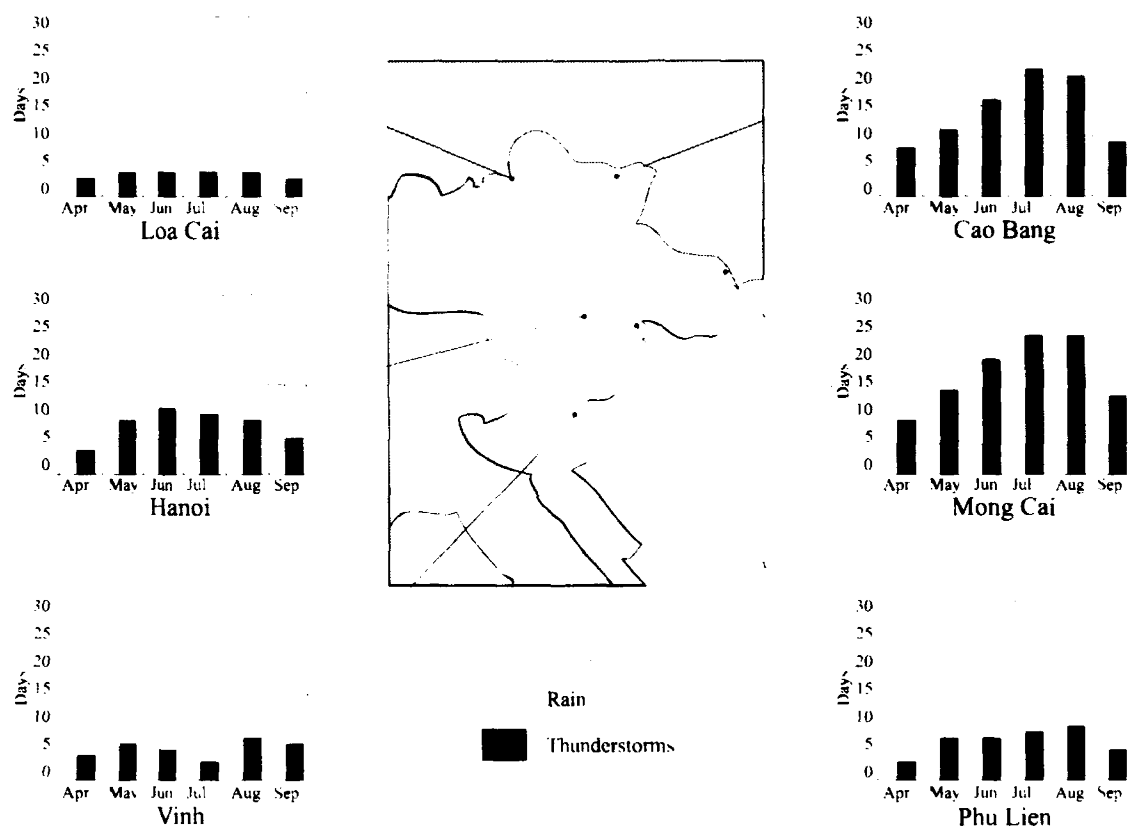


Figure 4-15. Southwest Monsoon Precipitation and Thunderstorm Days. The graphs show the number of days with rain and thunderstorms based on monthly average occurrences at scattered locations within northern Vietnam.

Temperatures. Northern Vietnam's highest temperatures occur in June, July, and August. Mean temperatures range between 24° and 31°C beginning in April. A few stations report means near 34°-35°C by high summer (July). Most extreme highs hover near 36°-37°C, but several locations report extreme maximums of 42°C or more. Hanoi and Lo Cai both report extreme maximums of 43°C. Southeasterly flow over the lowlands advects warm air from the Gulf of Tonkin into much of the area. At higher elevations to the north and west, however, temperatures are correspondingly lower, and the variable surface flow often brings in cooler air from the north to the mountains. Mean low temperatures remain in the 23°-28°C range. April extreme lows drop to 7°-8°C. After April, temperatures do not fall below 12°-14°C in the mountains or below the 18°-20°C elsewhere. The farther south and the lower the elevations, the more consistent the temperature is. Diurnal variation ranges from minimums of 31°-32°C at night to maximums between 35°-37°C range during the day.

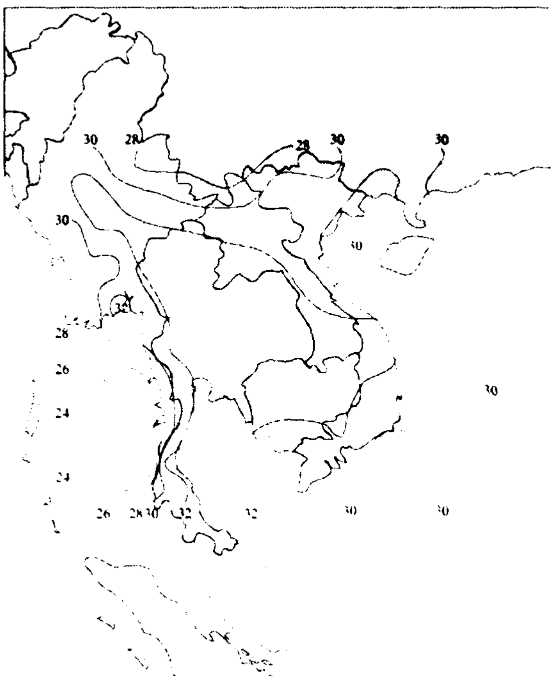


Figure 4-16. April Mean Maximum Temperatures (°C). The isopleths represent the average of all high temperatures during the dry season.

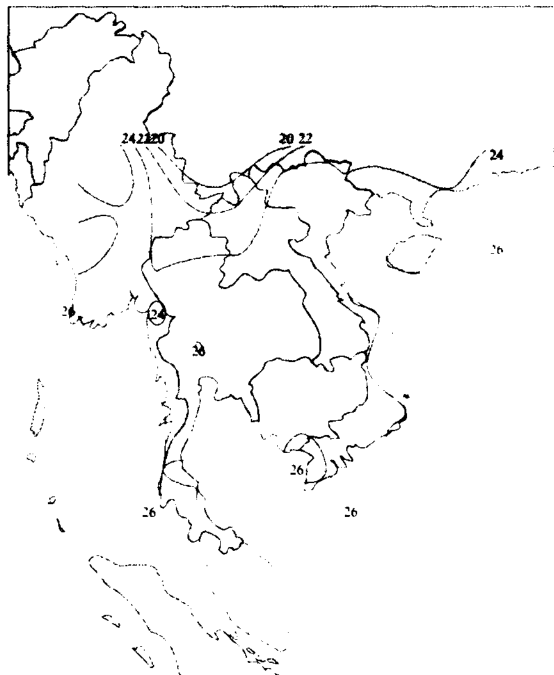


Figure 4-17. April Mean Minimum Temperatures (°C). The isopleths represent the average of all low temperatures during the dry season.

Other Hazards. Aside from the turbulence normal associated with mountain waves and thunderstorms, the primary southwest monsoon weather-related hazard in northern Vietnam is flooding. The heavy and frequent rainfall of the southwest monsoon swells rivers and streams in vast Red River delta, but even small amounts of precipitation in and around the deep, steep-walled valleys to the northwest can cause flash floods in the mountains. Mud slides and landslides frequently bury or destroy the roads, many of which are unpaved. Flooding incident to tropical cyclones also causes extensive damage along the coasts and throughout the lowlands.

Trafficability. Soils in this area are predominantly fine-grained silts and clays; however, there are some course-grained soils beneath the silts and clays in the Red River delta. Wet season precipitation adversely affects the fine-grained soils of this area. Fine-grained soils in a wet condition will not usually support repeated passes of military vehicles. The rugged topography in the far north and west contributes to a further decrease in trafficability. Overall, northern Vietnam's trafficability is fair to poor; fair conditions exist in the Red River delta.

Chapter 5

WEST-FACING COASTS

This chapter describes the geography, major climatic controls, special climatic features, and general weather by season for the west-facing coasts of southeast Asia, as shown below.

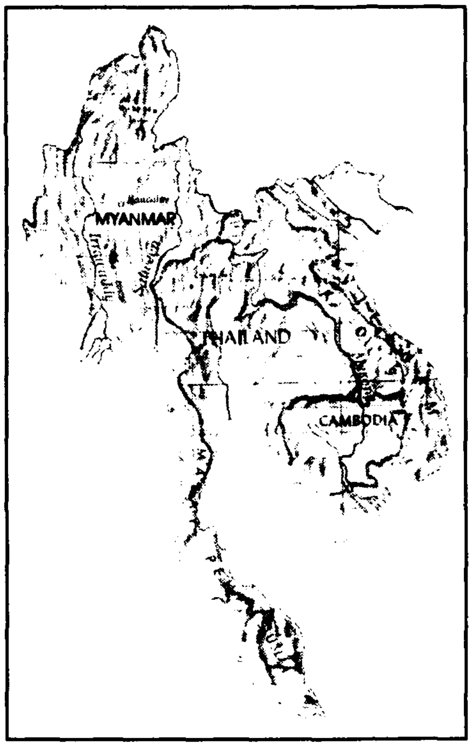


Figure 5-1. Topography. This map shows major place names, rivers, and terrain features.

Boundaries. This "zone of climatic commonality" comprises western Myanmar, southern and western Thailand, southern Cambodia, and southern Vietnam. Much of Myanmar and the southwest peninsula of Thailand face the Indian Ocean, while smaller portions of Thailand's southern coast, southwest Cambodia, and the southern tip of Vietnam face the Gulf of Thailand. The primary geographic features of the region are described below (refer to Figure 5-1 for the location of the areas discussed).

Topography. This region, stretching more than 1,600 km from north to south, is composed of very diverse terrain (see Figure 5-1). Myanmar's Arakan Coast and Hills region stretches from the Indian border to the southern end of the Arakan Mountains, facing the Bay of Bengal. Elevations range from just less than 2,700 meters in the north to 570 meters in the south. The continuous chain of the Chin Hills-Arakan Mountains backs a coastal plain 65 km wide at Maungdaw, narrowing to 15 km at Gwa.

The southern Shan plateau region of eastern Myanmar consists of mountains averaging less than 1,500 m in elevation. Across the border in northwestern Thailand, however, the mountains rise to more than 2,550 meters and include Doi Angka, the highest peak of the northwestern range (elevation 2,580 meters).

Myanmar's southern plains are composed mostly of lowlands lying below 76 meters in elevation. This region is comprised of the extreme southern quarter of the Irrawaddy River and Sittang River valleys. Bounded by the southern edges of the Arakan Mountains on the west and the Shan plateau on the east, the southern plains extend northward 240 to 280 km from the Gulf of Martaban into south-central Myanmar. Terrain is generally flat except near the bases of the Arakan range and in the area just south of the Pegu Mountains, which average 300-600 meters in elevation and divide the Irrawaddy River and Sittang River valleys. In the Irrawaddy

and Sittang deltas (total area 19,000 square km) the landscape is absolutely flat, with the monotony relieved only by a few blocks of erosion-resistant rocks less than 18 meters high.

The Tenasserim coastal region, in extreme southern Myanmar, consists of a broken chain of hills and low mountains. Elevations average 900-1,500 meters in the north but decrease progressively to about 300 meters in the south. This narrow finger of Myanmar stretches from the mouth of the Sittang River to Victoria Point (10° N, 98° E). Its width ranges from 160 km in the north to 30 km in the south. Rising rapidly from a narrow coastal plain, the Tenasserim Mountains act as the dividing line between rivers flowing to the Andaman Sea on the west and the Gulf of Thailand on the east. The highest peak on the Myanmarian side of the Tenasserim ranges, Myiamoletkat, rises to 2,075 meters. Only north of 16° N does the coastal plain exceed 40 km in width; from Moulmein northward to 17° N it averages 80 km wide.

Peninsular Thailand, extending southward to the border of Malaysia, is flanked by the Andaman Sea and southern Myanmar's Tenasserim Mountains on the west. On the east, a gently sloping sandy coastline borders the Gulf of Thailand. The topography of Thailand's peninsula is rolling to mountainous, with little flat land. Hills and low mountains, with elevations exceeding 1,500 meters on isolated peaks, are scattered throughout the region but are generally concentrated near the coasts. These highlands separate the interior from the coastal plains, which are only a few feet above sea level.

The southern Cambodian Mountain region encompasses the narrow coastal plains and highlands of southwestern Cambodia, a small part of southeastern Thailand, and several small offshore islands. The most prominent features of this region are the two discontinuous mountain ranges, the Cardamom Mountains and the Elephant Mountains. These ranges form a highland region that covers much of the land area between Cambodia's Tonle Sap Lake and the Gulf of Thailand. Elevations range from 300 to almost 1,800 meters, forming a barrier to the monsoonal flow. In this remote and largely uninhabited area stands Phnum Aoral (1,813 meters), Cambodia's highest peak, and Khao Soi Dao Mountain (1,668 meters) in southeast Thailand. The southern coastal region adjoining the Gulf of Thailand, however, is a narrow, moderately populated, lowland strip.

The central plains and lowlands region comprises the principal lowlands, plains, and delta areas of Cambodia, Thailand, and southern Vietnam. It includes the major drainage basins of the Mekong River, which are subject to annual flooding. Terrain features vary from flat or rolling plains and rain forests to rice fields, marshlands, and deltas; elevations are generally below 200 meters, and most areas are near sea level.

The two most dominant topographical features of this region are the Mekong River and Tonle Sap Lake. The Mekong's annual flooding deposits a rich alluvial sediment that accounts for the fertility of the central plain. The Mekong Delta is bounded by the South China Sea on the south and the Gulf of Thailand to the west. The delta has hundreds of canals and inland waterways crisscrossing southwestern Vietnam. These canals are used as the main arteries for local commerce and are invaluable for draining and irrigating the rice paddies covering the Mekong Delta.

Rivers and Drainage Systems. The mountains of the Shan Plateau are drained by a system of southward flowing rivers, including the Salween, which enters Myanmar from Yunnan in China and empties into the Gulf of Martaban southeast of the Sittang. The Salween crosses the plateau in a series of deep gorges; many of its tributaries are more than 480 km long and enter the Salween in cascades. Throughout the Arakan Coast, isolated hills and low mountains dot the plains, which are drained by short, rapid streams. These streams then form broad deltas and flow into the Bay of Bengal.

In the southern plains, the Irrawaddy Delta breaks up into a network of streams emptying into the Andaman Sea through nine mouths. The Bassein River, which drains the southern Arakan Mountains, and the Rangoon River, which drains the Pegu Mountains, enter the Irrawaddy at its delta. The

Sittang flows into the Gulf of Martaban on the Andaman Sea through a large valley and a huge delta, in spite of its comparatively short length. The Tenasserim plains are drained by short, rapid rivers that enter the Gulf of Martaban.

Along the southern Cambodian coastline, the short, seaward-running streams indenting the coast have built up small alluvial basins and deltas, while the mouths of larger rivers consist of tidal flats and mangrove swamps.

Rising in Tibet and emptying into the South China Sea, the Mekong River enters Cambodia from Laos and flows broadly southward to the Vietnam border, covering approximately 500 km inside Cambodia. Tonle Sap Lake is joined to the Mekong by the Tonle Sab River. During the rainy season (mid-May to early October), the enormous volume of water from the Mekong causes the Tonle Sab River to back up and flow into the lake. The lake's surface area expands from the dry season minimum of about 3,000 square km to a rainy season maximum of more than 7,600 square km; its maximum depth increases from 2 meters in the dry season to up to 10 meters. As the water level of the Mekong falls during the dry season, the process is reversed, and water drains from Tonle Sap Lake back into the Mekong, reversing the flow of the Tonle Sab River.

Vegetation. Tidal forests of mangrove trees grow as high as the 30-meter elevation line in Myanmar's southern plains. Cambodia's southern coast is a narrow, heavily wooded lowland strip. Open forests of pines are found at higher elevations, while the rain-drenched seaward slopes of the southern Cambodian Mountains are blanketed with virgin rain forest growing to heights of 45 meters or more. Vegetation in the Mekong Delta includes mangoes and bananas, along with papayas and other forms of tropical fruits. Near the southern end of the delta, mangrove swamps penetrate 8 to 16 km inland, with the most extensive areas of mangroves found on the southern tip of the Mekong Delta.

Sea-Surface Conditions. Surface temperatures of coastal waters are uniformly high throughout the year. The mean annual temperature is near 27°C, with less than 5°C difference between the highest and lowest monthly averages. The lowest values are reported in December and January, when sea-surface temperatures vary from 24°C in the extreme northern coastal waters, to slightly over 27°C in the south. The highest values occur in April, May, and June, when temperatures are near 29°C along the entire coast. Sea conditions near the coast are usually slight during the northeast monsoon, slight to moderate during the transitional seasons, and slight to rough during the southwest monsoon.

Asiatic High. This high, caused by strong radiative cooling of the Asian continent, exists from about September to April (see Figures 2-4a-d for mean positions). Its cold, dry outflow is the primary source of the northeast monsoonal flow over this climatic zone from November to March.

India-Myanmar Trough. This quasi-stationary trough forms at about 85° E during the southwest monsoon. Strengthening the tropical easterly jet, it is a preferred area for development of monsoon depressions.

Near Equatorial Tradewind Convergence (NETWC). The northern NETWC divides the dry continental air to the north from the moist, tropical maritime air to the south. The changing position of the northern NETWC determines the wet and dry seasons in this climatic zone. Its mean position is completely north of the area from June through September (see Figure 2-10).

South Indian Ocean (Mascarene) High. Outflow from this high meets outflow from the Asiatic high to form the NETWC. This is the southwest monsoon's primary moisture source, as the moisture-laden outflow pushes the NETWC northward over this climatic zone.

Southern Oscillation. (See Figure 2-5 and the discussion in Chapter 2.) El Niño causes radical changes in the monsoon cycle in this climatic zone. It reaches its peak in this region from June to August and lasts until November or December. El Niño causes droughts in this climatic zone during the southwest monsoon, and the months December-February following El Niño are unusually hot.

Tropical Easterly Jet (TEJ). Oscillating between 5° and 20° N at about 200 mb (14-15 km), the TEJ's mean position is across the southern part of this climatic zone at about 15° N (see Figure 2-22). Changes in the TEJ cause surges in convection and rainfall.

Thailand Heat Lows. These lows form over western Thailand and Myanmar from May to July due to increasing solar insolation and decreasing cloudiness. As the southwest monsoon progresses northward, these lows are displaced into China. Figure 2-7 shows the mean position of these lows during the southwest monsoon.

Tropical Cyclones. Tropical depressions (wind speeds less than 34 knots), tropical storms (wind speeds of 34-64 knots), and typhoons (wind speeds 64 knots or more) usually affect this climatic zone during the southwest monsoon, though they may continue into the early northeast monsoon and occur again at the end of the northeast monsoon.

Most storms affecting the area develop east of the Philippines, but some originate over the South China Sea. Although Vietnam suffers the worst effects of these storms, Cambodia, Laos, Thailand, and Myanmar can also be affected. Other depressions form in the Indian Ocean or the Bay of Bengal and move northward or northeastward toward northern Myanmar and the Arakan Mountains. Monsoon depressions form at about 20° N, 90° W during the southwest monsoon. They usually move toward India, but they can recurve toward the north or northeast and hit the northern Myanmar coast. At sea, monsoon depressions can develop into tropical storms, but their wind intensities decrease over land. Cloud patterns associated with monsoon depressions are chaotic, but they can cause rainfall for a week or more.

During the southwest monsoon, tropical storms and typhoons usually affect southeast Asia from July through September. Although Vietnam (north of 15° N) is most threatened during this period, southern Vietnam, Cambodia, and Thailand are affected during September as the transition to the northeast monsoon begins and the main cyclone tracks shift southward. During September, the cyclones tend to move farther inland, making this the wettest month of the year in this part of the region. Storms from the South China Sea can regenerate in the Bay of Bengal after moving across the region as weakened depressions and cause extensive cloudiness.

In October, the main cyclone tracks continue to shift southward and affect the southern part the area. Tropical storms and typhoons move farther inland before dissipating. Occasionally, a tropical storm may form in the Gulf of Thailand and move northwestward over peninsular Thailand. Cyclonic activity is confined to the southern part of the area in November and December. During these months, tropical storms and typhoons are generally weaker than those in previous months and tend to follow more erratic courses. Southern Vietnam bears the brunt of these cyclones, although some move farther inland into eastern Cambodia.

Unlike most of Thailand, peninsular Thailand has no protective barrier to the east. The movement of the storm tracks toward the south in the advanced typhoon season (October through December) leaves peninsular Thailand extremely susceptible to tropical cyclones. Fortunately, typhoon frequencies decrease toward the equator. Although available records indicate that no storms of full typhoon intensity have reached peninsular Thailand, tropical depressions and occasional tropical storms do cross the peninsula, spreading destruction and very heavy rainfall.

Historically, tropical cyclones play only a minor role in Myanmar's weather during the northeast monsoon, affecting the country only in November and December. From 1891 through 1960, only five depressions and one tropical storm affected the Bay of Bengal east of 90° E from January through March. The storms usually form in the southeastern Bay of Bengal and move northward or eastward to strike the Arakan coast. The most severe tropical cyclones usually form in the central part of the Bay of Bengal.

Typhoons entering Thailand from the west are generally those that have recurved after striking the Myanmar coast. As with the storms entering Thailand from the Pacific, they lose much of their intensity when crossing the mountains. These storms occur infrequently, usually once every 6 to 8 years, and they always occur from April to June or October to December.

Typhoons dissipate after moving onshore, but remnants of the storms may affect the west-facing coasts for several days. Winds of typhoon strength can be expected within 50 km of the storm center, and winds of 25 knots can be expected up to 250 km from the center. Dense clouds can be expected from the surface to well above 6 km within 170 km of storm centers. Torrential rains may occur over wide areas, particularly in mountains, resulting in flooding along river channels and in delta and coastal regions. Abnormal tides associated with high seas and swells also contribute to flooding in delta and coastal regions.

Mountain/Valley and Slope Winds. Like land/sea breezes, these local winds dominate the weather during periods of weak general circulation. These winds are most likely to occur near the equator during the intermonsoon periods. Especially susceptible is peninsular Thailand, where nocturnal mountain winds flowing toward the sea cause lines of thunderstorms to form.

Land/Sea Breezes. The region experiences land/sea breezes year-round, but they are most prominent in the intermonsoon periods of April-May and September-October, when the general circulation patterns are weak and local winds prevail. During the northeast monsoon, the land breeze enhances the general northeasterly flow, but the northeasterly flow weakens or nullifies the sea breeze. During the southwest monsoon, the sea breeze augments the southwesterly monsoonal flow.

Foehns. These hot, dry winds occur on the lee sides of mountains in southeastern Thailand during the northeast monsoon and the Cardamon Mountains in southwestern Cambodia during the southwest monsoon.

General Weather. During the northeast monsoon, the Himalayas shield much of southeast Asia from the full effects of cold outbreaks from the Siberian high. The air reaching southeast Asia from the north is warmed considerably as it descends the mountain slopes, but it remains dry, bringing fewer than 2 days of rain a month to much of this climatic zone.

Although the period from October through March generally defines the northeast monsoon, the average length of this season may vary as much as 2 or 3 weeks in some parts of the region. In addition to changes in the monsoonal circulation itself from year to year, differences in latitude, topography, and exposure to oceanic influences can cause variations in the onset and demise of the monsoons affecting this part of the globe. The transition from the southwest to the northeast monsoon and back again is a gradual process, not characterized by distinct changes in weather patterns over a day or two. Instead, short transition seasons with varying influences from both the outgoing monsoon and the incoming monsoon typify the interim period. Given the large latitudinal spread within this region, one monsoon season may be well-established in one sector, while areas far in the opposite direction may still be under the influence of the associated transition season.

Modified continental polar air dominates the climate during the northeast monsoon. The flow pattern represents a dynamic balance between the semipermanent, cold, Siberian high and the warm equatorial trough of low pressure. Although originating as an extremely cold, dry air mass in Siberia, much of the air undergoes great modification during its equatorward movement over the warm waters of the Pacific Ocean and South China Sea. As the air descends the high mountains north and east of Myanmar and the Annam Mountains of Vietnam, it becomes considerably warmer and drier. Cloudiness and precipitation associated with the northeasterly flow generally occur on the eastern slopes and little is experienced over the west-facing coasts. Nevertheless, some orographic cloudiness and rainfall occur on the eastern slopes of Cambodia's southwestern mountains. As the air mass continues to travel southwest, it acquires moisture over the Gulf of Thailand causing heavy rain and extensive cloudiness along the exposed windward slopes of peninsular Thailand and to some extent in extreme southern Myanmar.

Since this region lies mostly within the tropics, its climate is significantly influenced by the high angle of the sun. The strong insolation and proximity to warm waters limit the daily and seasonal variations in temperature and relative humidity, particularly near the coast. The Bay of Bengal and the Andaman Sea are especially effective in moderating temperatures over Myanmar's coasts.

Tropical waves occasionally affect the region, principally during the latter months of the year, bringing increased shower and thunderstorm activity. Occasionally, these easterly moving waves generate circulations that intensify and reach the area as tropical storms or typhoons.

Sky Cover. As the southwest monsoon weakens and cool, dry air arrives from the northeast, cloudiness decreases markedly. This reduction usually occurs in October and November over most of the area, but peninsular Thailand, which is further south, does not experience this large decrease until January. Skies are very often clear over much of this region during the northeast monsoon; many locations in the plains and lowlands report clear skies 15 days a month from January through March. In the southern Cambodian Mountains, peninsular Thailand, and much of the Tenasserim coast, however, fewer than 5 clear days a month occur. On average, the Tenasserim coast has about 12 cloudy (total cloud cover greater than 6/8) days a month, with the number of cloudy days generally decreasing from south to north. Cloudy skies are less prevalent elsewhere, but notable exceptions are the Shan plateau's Loi-kaw area and Vietnam's southern peninsula, where as many as 22 cloudy days occur during November and December.

The diurnal variation of mean cloudiness is most pronounced during the latter part of the northeast monsoon and is generally more marked than during the southwest monsoon. Maximum cloud cover can generally be expected during the afternoon, while minimum daily cloud occurs during the night and early morning. However, in sheltered areas along river valleys and in parts of the Shan Plateau, low stratiform clouds are common at night and in the early morning. The clouds reach their maximum extent near daybreak and dissipate soon after sunrise, leaving the remainder of the day cloudless (see the data for Mae Hong Son in Figure 5-2). Locations reporting a high frequency of low stratiform cloudiness in the early morning usually show the largest diurnal variations. Nighttime instability over coastal waters often causes a nocturnal maximum of cumulus activity near the coasts of Myanmar; the opposite occurs over land areas, where cumulus develops during the afternoon. Figure 5-3 shows regional percent frequency of all ceilings, at all levels.

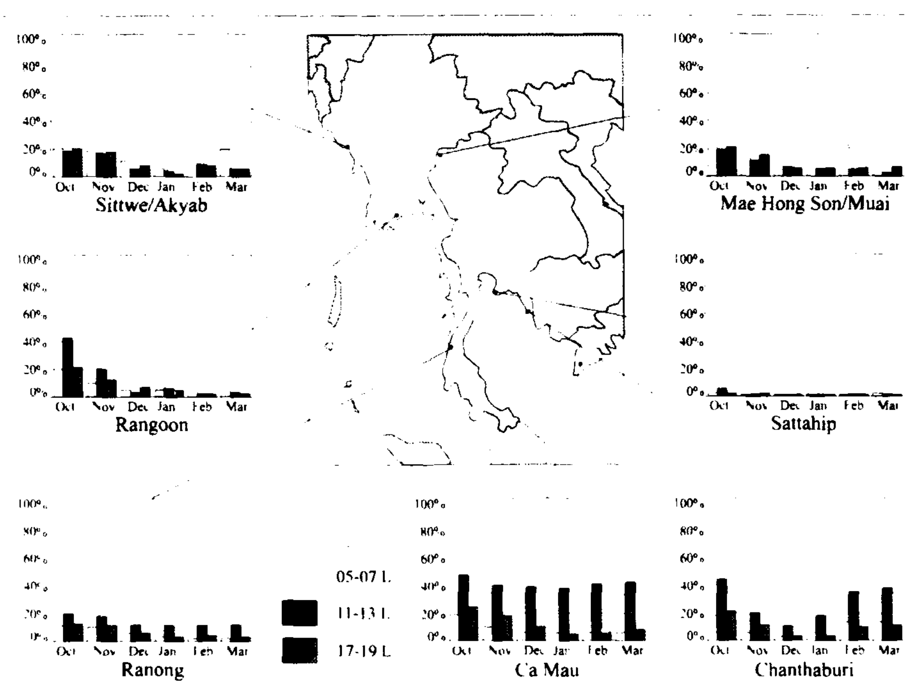


Figure 5-2. Northeast Monsoon Ceilings below 3,000 Feet. The graphs show monthly percentage of ceilings below 3,000 feet based on location and diurnal influences.

The predominant cloud types over Myanmar are cirriform, with an occasional middle cloud deck associated with the southern end of a strong trough in the westerlies. These clouds are almost always evident in varying amounts throughout the season. Fair weather cumulus is common during the afternoon, but it usually dissipates by sunset. Cumulonimbus clouds develop frequently in southern Tenasserim, especially in March. Cloud bases average 8,000 to 10,000 feet MSL over central Myanmar and the Shan Plateau, with layers extending to 30,000 to 35,000 feet. Stratus and stratocumulus clouds form by late evening, with bases at 2,000 feet MSL and tops between 2,500 and 3,000 feet MSL. These clouds lower to between 500 and 1,000 feet by 0600L. Isolated 300- to 500-foot ceilings occur along the coast of the southern plains and about 25 (40 km) miles inland during February and March between 0600 and 0800L. Mountains between 800 and 2,500 feet are obscured. These lower level clouds generally clear by noon, but during February and March clearing may not occur until midafternoon along the coasts.

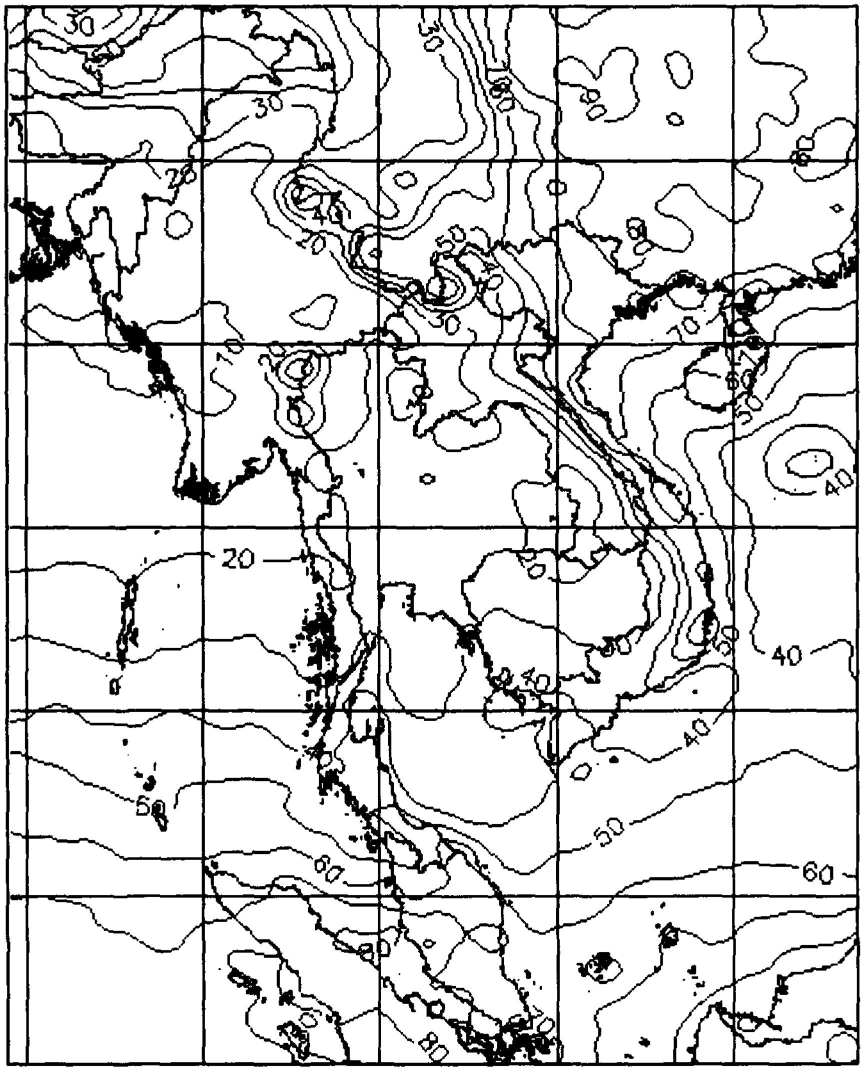


Figure 5-3. January 00Z Ceilings. Figure shows percent frequency of ceilings at all levels.

Visibility. Large variations in visibility occur throughout the region due to the great differences in land and water distribution, elevation, exposure, and vegetation. These variations, however, are often very local in nature. Restrictions are most prevalent in the mountains of northwest Thailand. Early morning visibilities at Mae Hong Son are below 800 meters more than 60 percent of the time from October through January (see Figure 5-4 on next page). Reduced visibilities are also fairly common in Myanmar, but the remainder of this climatic zone rarely experiences visibilities below 4,800 meters. In general, low ceilings and reduced visibilities oc[illegible]ch less often during the northeast monsoon th[illegible]ing the southwest monsoon.

Coastal areas are relatively free of fog, but sheltered interior valleys and inland delta areas frequently have early morning fog during this season. Fog usually gives way to afternoon smoke and haze from burning vegetation. Smoke and haze represent the main visibility restrictions during daylight hours, as the lack of heavy or frequent rains results in little clearing of the air. Radiation fog commonly forms in the mountains around large river basins, since these regions are frequently clear at night and surface winds are very light. Fog also occurs when continuous precipitation saturates the air, but this type of fog is not as common, nor does it restrict visibility as much as radiation fog. Precipitation does not restrict visibility to a great degree. Dust occurs infrequently and is usually of a localized nature, because there are no large dust-producing regions in or near the area.

Subsidence of the relatively cool, northeast monsoonal air tends to produce a temperature inversion near 2,000 meters (the average top of the monsoonal flow). Haze, with visibilities of 1,600 to 4,800 meters, can occasionally be expected below this inversion base. Slash-and-burn farming techniques, used to clear fields, contribute to reduced visibilities aloft as well as at the surface. Fields are generally burned when the dry season is nearing its end and rice stalks are most conducive to burning. Natural grass, brush, and forest fires also contribute to reduced visibilities aloft during this season.

Under the low cloud decks, visibilities range from 1,600 to 4,800 meters in salt haze and fog near sunrise to 8-11 km in haze in late afternoon. Above 1,000 meters, in the northeast monsoonal flow, visibilities are above 16 km.

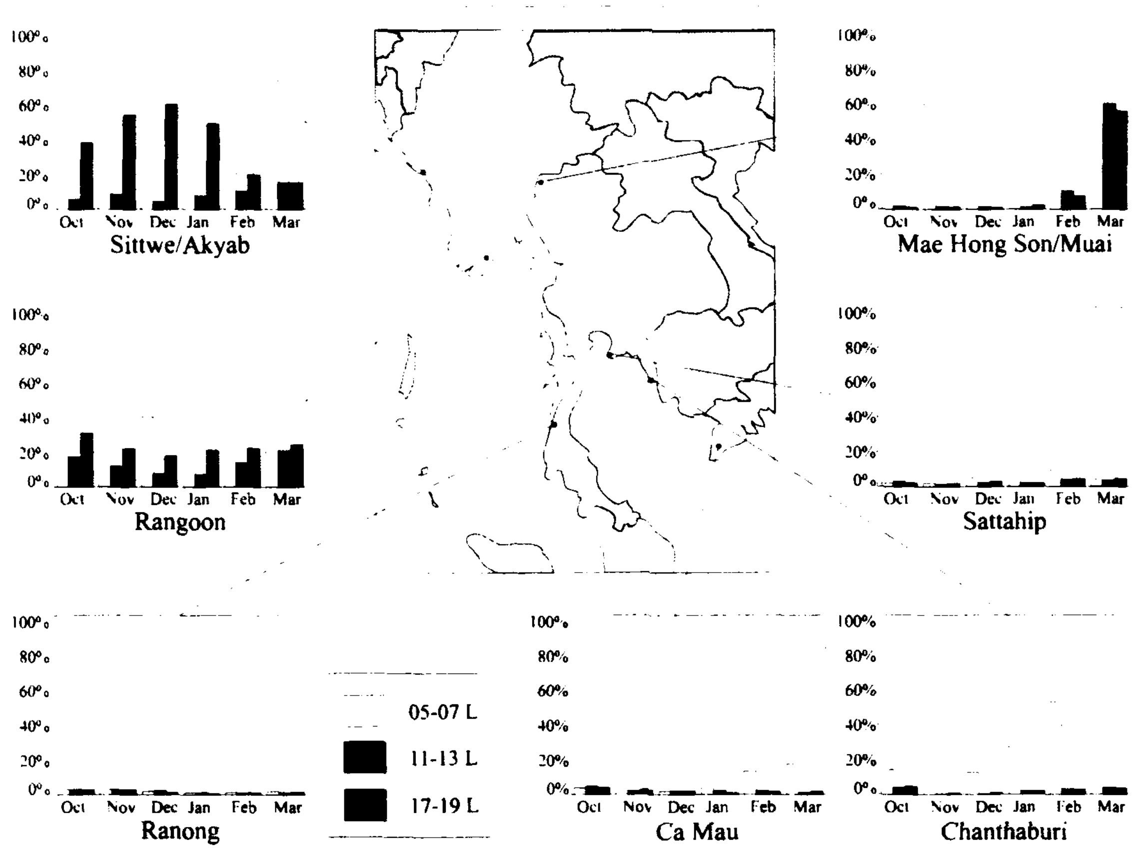


Figure 5-4. Northeast Monsoon Visibility below 3 Miles (4,800 Meters). The graphs show a monthly breakdown of the percentage of visibility below 3 miles (4,800 meters) based on location and diurnal influences.

Winds. During the northeast monsoon, surface winds over most of the area are light, with the strongest winds usually occurring along or near the coasts. Although directions are somewhat variable, winds are generally from the north or northeast over Myanmar. Below 1,000 meters, the winds reflect a marked land/sea breeze circulation along the coasts, with mountain/valley breezes inland. Late morning through early evening winds are onshore--normally southerly to westerly--at 7 to 12 knots, or up-valley at 5 to 8 knots. Late evening through early morning winds are either northerly to easterly and calm or down-mountain at 3 to 5 knots. Northeast monsoon winds are northeasterly to easterly at 5 to 10 knots above 1,000 meters AGL. Diurnal variations in wind direction and speed can also be discerned in coastal areas of Thailand, Cambodia, and southern Vietnam, with onshore winds prevailing from midmorning through afternoon and offshore winds during the night and early morning. Channeling is inevitable in the mountains, and local topography often causes prevailing surface directions to be other than northeasterly. Figures 5-5 and 5-6 show January 00Z and 12Z surface wind roses, respectively.

Nights are frequently calm and daytime winds are often light; however, strong winds have occurred during the northeast monsoon. Phu Quoc, an island in the Gulf of Thailand off the coast of Cambodia, recorded a wind of 73 knots in February. Bhumipol Dam in northwestern Thailand and Khlong Yai in southeastern Thailand have experienced 72- and 70-knot winds, respectively. Winds have reached 60 knots at Sittwe in October, November, and March and at Rangoon in December and February.

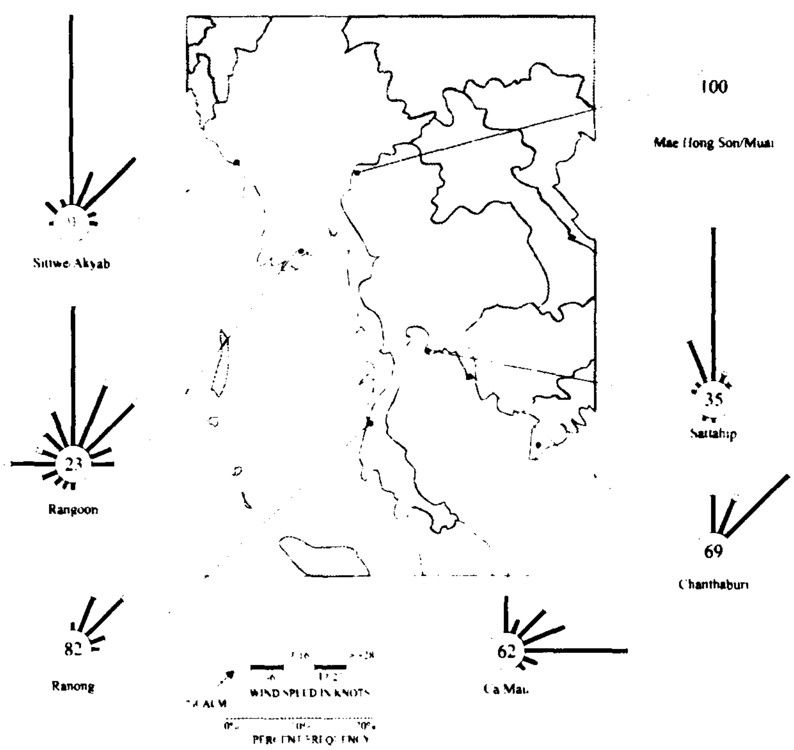


Figure 5-5. January 00Z Surface Wind Roses. The wind roses show the prevailing wind direction and range of speeds based on time, frequency, and location.

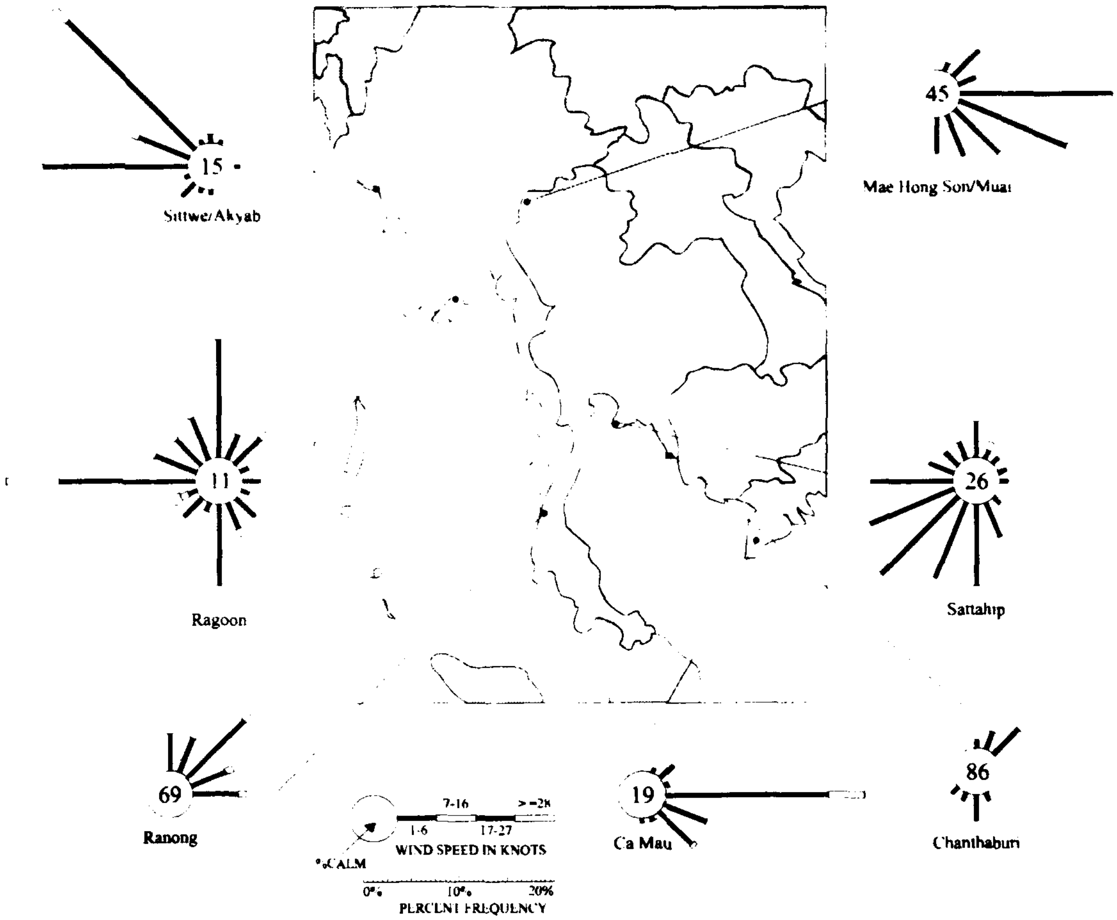
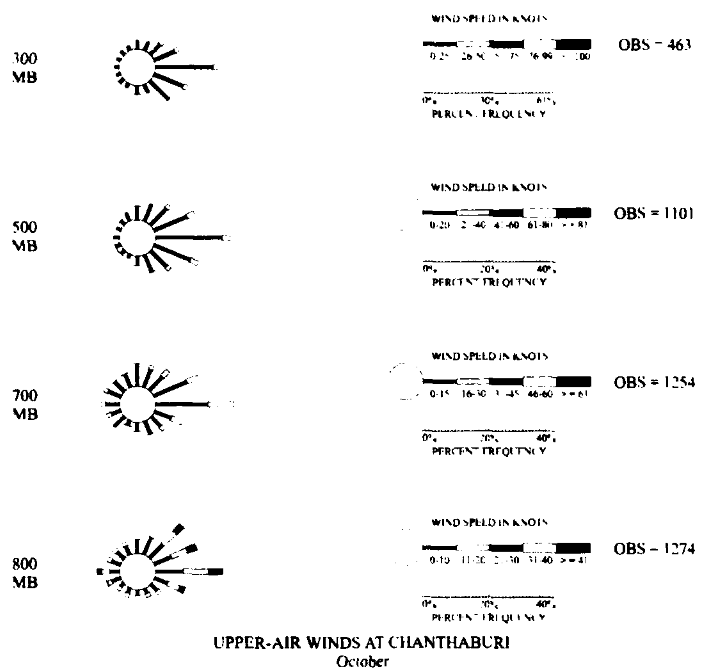


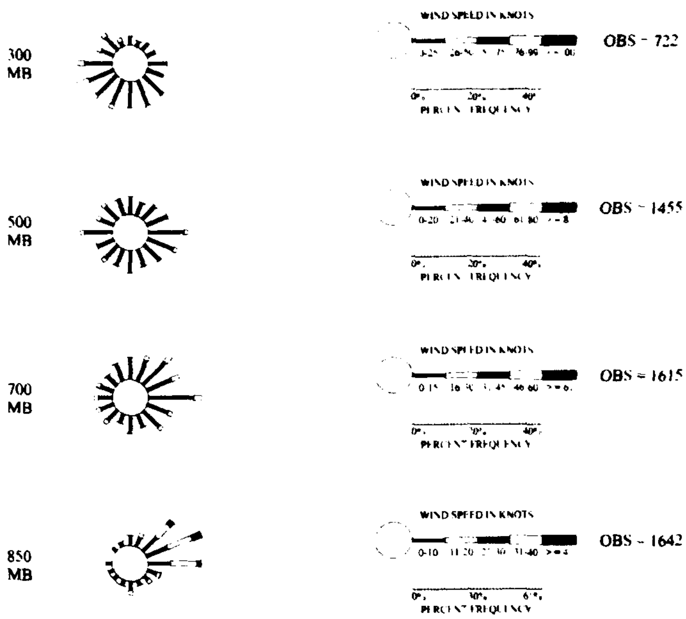
Figure 5-6. January 12Z Surface Wind Roses. The wind roses show the prevailing wind direction and range of speeds based on time, frequency, and location.

Upper-Level Winds. North of the Tenasserim coast, at about 1,500 meters AGL, wind speeds increase slightly, and the direction changes so that winds blow mostly from the south or southwest. Between 1,500 and 2,400 meters, winds veer to westerly and speeds increase, in some cases to about 50 knots. The relatively shallow airflow of the northeast monsoon rarely extends to this level, and westerlies prevail over this part of the area to at least 16 km. Speeds increase considerably at higher altitudes. Between 12° and 15° N from about 3 to 18 km, winds gradually transition from easterlies to westerlies. South of about 12° N, tropical easterlies occur up to 18 km.

Wind speeds are relatively light at low levels but increase with height. Maximum speeds occur between about 11 and 14 km in the westerlies and at about 14 km in the easterlies. However, the upper-level easterlies in the south are much lighter than the upper-level westerlies in the north. Figures 5-7 and 5-8 show October and January upper-air wind roses for Chanthaburi, Thailand, respectively. Wind speeds exceeding 100 knots rarely occur south of about 19° N during the northeast monsoon. North of 19°N, winds of 100 to 150 knots occur approximately 5 to 10 percent of the time between 9 and 15 km. In the north, winds exceeding 150 knots are extremely rare.



Figures 5-7. October Upper-Air Wind Roses. The wind roses depict wind speeds and directions for standard pressure surfaces between 850 and 300 mb at Chanthaburi, Thailand. Note: Each wind rose has a tailored legend.



Figures 5-8. January Upper-Air Wind Roses. The wind roses depict wind speeds and directions for standard pressure surfaces between 850 and 300 mb at Chanthaburi, Thailand. Note: Each wind rose has a tailored legend.

Precipitation. Mean rainfall amounts drop considerably from November to December. In January and February, most locations report less than 25 mm of precipitation, and many areas (particularly southern Vietnam and the majority of Myanmar's west facing coasts) average less than 12 mm. Notable exceptions include the southern Cambodian Mountains and peninsular Thailand. Moderate precipitation is also recorded in the eastern portion of the Shan Plateau and in the coastal areas of Tenasserim. Mergui, in the far south, is notable for its moderately abundant rainfall. Small cyclonic circulations that skirt the coast during periods of weak monsoonal flow sometimes cause the equivalent of an entire month's rain to fall in one or two isolated showers. Figures 5-9 and 5-10 show mean accumulations in October and January. As with rainfall amounts, the number of days with rain generally decreases during the northeast monsoon. Most locations show a sharp drop at the beginning of the season and a gradual increase as the spring transition ushers in the southwest monsoon. The Ca Mau and Ranong areas, however, see more days with rain than other areas due to the northeast monsoon's trajectory over the South China Sea and the Gulf of Thailand.

By mid-March, the NETWC has normally moved far enough north to place it near the Irrawaddy Delta. March remains a dry month for the area as a whole, but there is a gradual increase in rainfall amounts in all areas except the south central plains in Myanmar. Along the southern coast of Myanmar, winds are quite variable during the month. Air flow from the sea, together with convective activity, produce an average March rainfall of 127 mm at the town of Tenasserim.

Hail reaches the surface only rarely in Myanmar but probably occurs much more frequently at upper levels. Because the freezing level seldom drops below 4.5 km, most hail melts while descending through the deep layer of warm air and reaches the surface as rain.

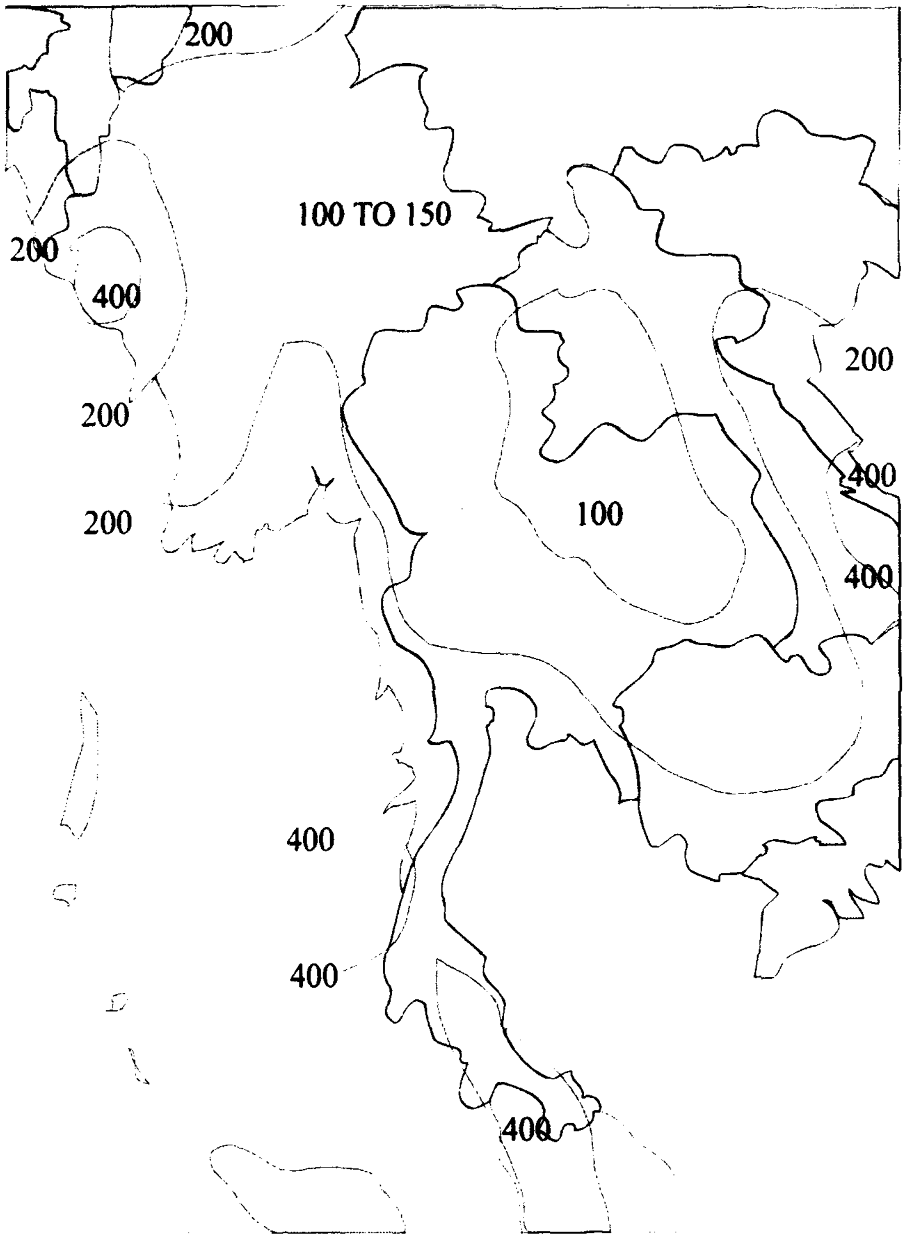


Figure 5-9. October Mean Precipitation (mm). The contours show the influence of the northeast monsoon on precipitation amounts.

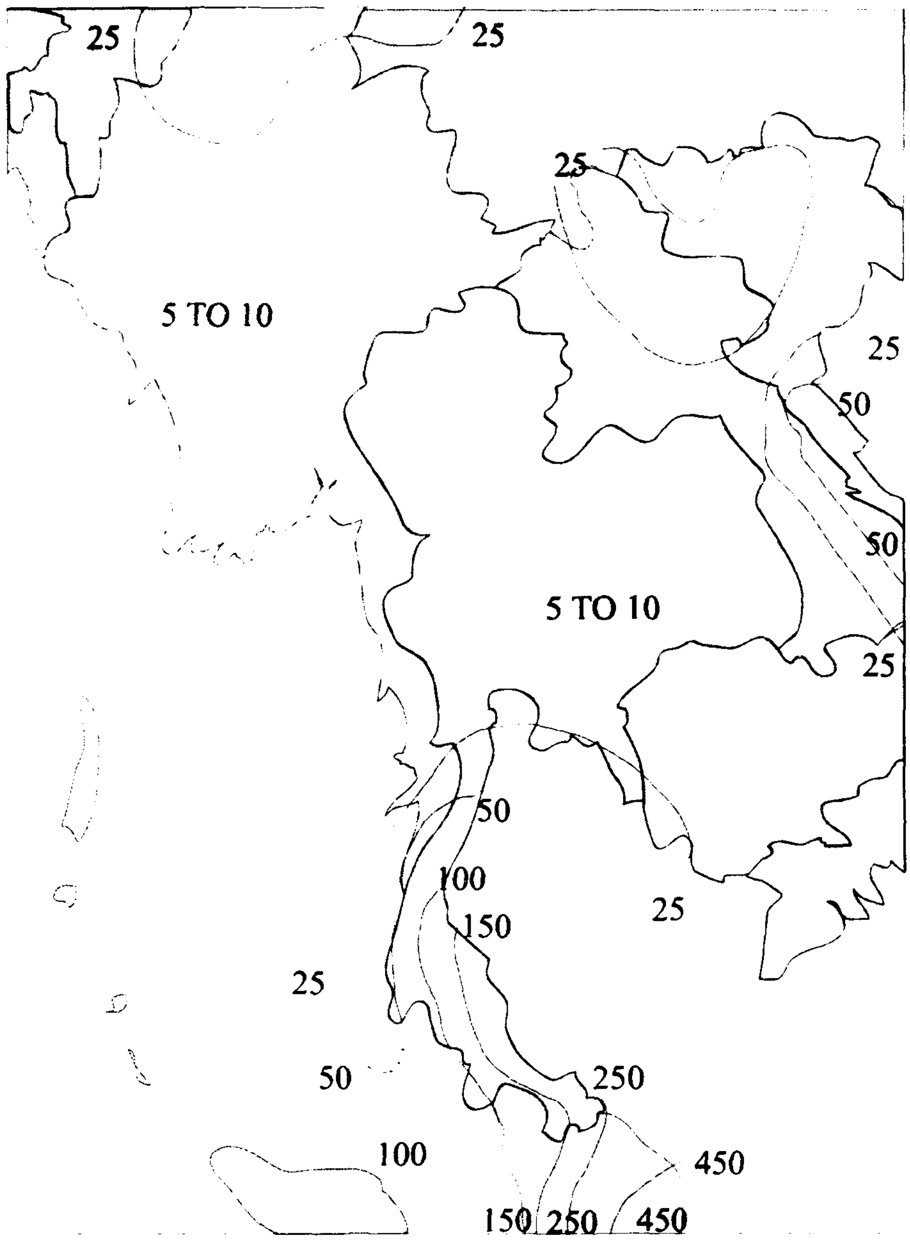


Figure 5-10. January Mean Precipitation (mm). The contours show the influence of the northeast monsoon on precipitation amounts.

Thunderstorms. Along Myanmar's southeast and northwest coasts, very isolated late afternoon thunderstorms form over the mountains. Thunderstorms are rare over the central plains and Shan Plateau. They have occurred in November, but their frequency is less than 1 percent. Here and along the coasts, thunderstorms form during periods of weak northeasterly flow and drift southwestward over the coast by late afternoon (see Figure 5-11). Thunderstorm tops throughout Myanmar reach 35,000-40,000 feet.

Thunderstorms are rather infrequent over coastal areas of Thailand, Cambodia, and southern Vietnam, where onshore winds prevail. By March, however, the northeast monsoon becomes more easterly and wind speeds decrease. This allows the formation of afternoon thunderstorms called "plum rains," which indicate the approaching end of the dry season. Thunderstorm frequency increases from one or two a month to about nine a month by April.

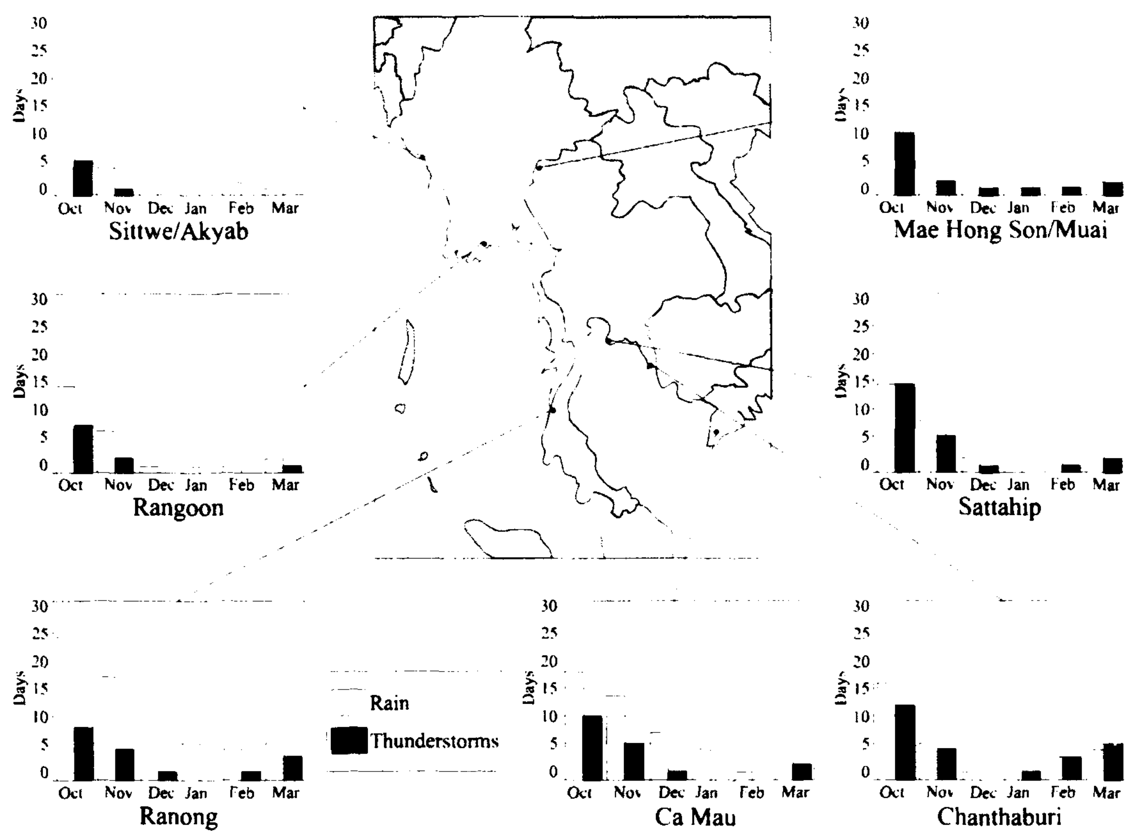


Figure 5-11. Northeast Monsoon Precipitation and Thunderstorm Days. The graphs show the number of days with rain and thunderstorms based on monthly averages at scattered locations.

Temperatures. Mean maximum temperatures from October through March range from near 25°C in the north to near 30°C further south. An extreme maximum temperature of 40°C has been recorded at several places throughout this zone, including Rangoon, Mae Hong Son, Mae Sariang, Ranong, and Bhumipol Dam. Mean minimums range from 14°-20°C on the Shan Plateau to 21°-26°C along the Gulf of Thailand. Figures 5-12 and 5-13 graphically depict mean maximum and minimum temperatures.

In general, the variation in temperatures from month to month is very slight. Sattahip, Chanthaburi, and Khlong Yai have only 1 Celsius degree variation in their mean maximum temperature ranges throughout the season. The islands of Ko Lanta and Phuket show the same small variation in their mean minimum temperatures.

The average height at which freezing temperatures are encountered in Thailand is close to 5 km year-round, though variations from this height are most likely to occur during the northeast monsoon. In the south, freezing temperatures are occasionally present at 3,600 meters. Although the probability of icing is lowest during the northeast monsoon (when the air is normally dry), icing is occasionally encountered between 3,600 and 7,600 meters MSL, particularly in cumulonimbus clouds. The mean height of the tropopause is around 17 km during the northeast monsoon.

The high daytime temperatures are accompanied by high humidities, leading to uncomfortable conditions. The maximum wet-bulb globe temperature (WBGT) often reaches 28°C, a level at which discretion should be used when planning heavy exercise (see Chapter 2 for a discussion of WBGT).

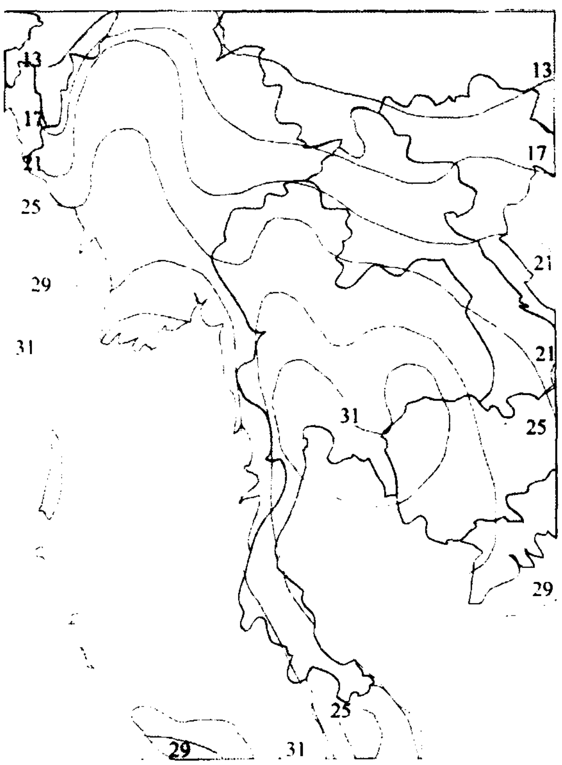


Figure 5-12. January Mean Maximum Temperatures (°C). Isopleths represent the average of all high temperatures during the most representative month of the northeast monsoon.

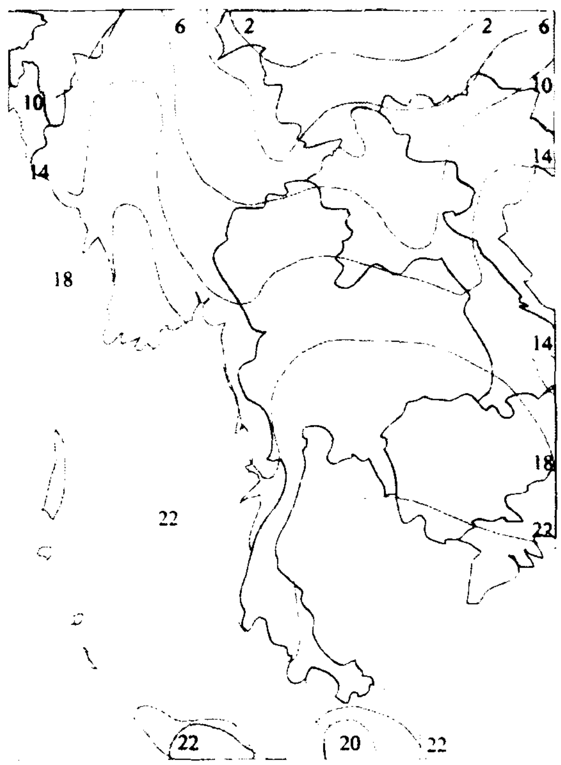


Figure 5-13. January Mean Minimum Temperatures (°C). Isopleths represent the average of all low temperatures during the most representative month of the northeast monsoon.

Other Hazards.

Turbulence. Moderate to severe turbulence is often reported over the mountains in the northern part of the Tenasserim coast and the Arakan coast and hills region. In addition, the Shan Plateau experiences occasional moderate to severe turbulence. Air crossing the mountains is warmed by adiabatic compression as it descends the lee slopes. As it becomes warmer than the surrounding air, it tends to rise again, causing turbulence, which may distort the airflow to well above 6 km. The immediate lee side of the ridge, where the downdraft occurs, is a particularly dangerous area for aircraft; however, moderate to severe turbulence will often be encountered for several miles downstream.

Clear-air turbulence can usually be expected to some degree in the vicinity of the tropopause and jet stream. This turbulence is often light near the tropopause; however, in the vicinity of a strong jet stream, it may be severe or even extreme. Over southeast Asia, 150-knot winds are not uncommon in the jet stream during the northeast monsoon, and speeds exceeding 200 knots have been recorded.

Tornadoes. Tornadoes are most prevalent during the spring transition season, but they have been reported throughout the year over all regions of southeast Asia. They are most common along southern coastal regions, particularly the Ca Mau Peninsula of southern Vietnam and the lowlands of Thailand. Generally they are not as intense as similar storms in the midwestern United States, but tornadoes are a threat, and they have caused loss of life. Tornadoes frequently form as waterspouts offshore and can occur in association with typhoons.

Floods. At some locations, principally in Cambodia and southern Vietnam, high water from the southwest monsoon may extend into December; on the peninsula of Thailand they may extend into January. The regions most susceptible to widespread flooding are the lowlands and deltas in the southern reaches of local rivers, like the Mekong, and at isolated locations along the coastal lowlands, where short streams empty into the sea. Flash flooding is common in the relatively short, narrow streams in the mountains, especially when thunderstorms or tropical cyclones produce excessive rainfall in short periods of time.

Trafficability. Cross-country travel through the southern plains of Vietnam is seriously restricted by the network of rivers, canals, and irrigation ditches. The Mekong Delta is so poorly drained that more than half of its surface is flooded every year in the late summer and again in the late fall. Ocean tides penetrate all the waterways and raise their levels about 2 meters during the dry season and 1.5 meters at flood times, making all surface water brackish and unpotable. Natural levees, 1.5 to 4.5 meters high have developed along the banks of the Mekong and Bassac rivers, and their tops are used for footpaths and main roads. During the winter months, when the prevailing winds shift to northeasterly, the air dries out due to the orographic effect created by the Annam Mountains along the eastern coast of Vietnam. This situation produces a dry season in the deltas, and the land becomes navigable. In addition to evergreen forests along the coastal strip of Cambodia's southwestern mountains, the vegetation includes nearly impenetrable mangrove forests.

General Weather. The southwest monsoon includes the months of June through September and the intermonsoon period of April and May. Cloudy, hot, humid, and rainy conditions prevail during the southwest monsoon. The only relief from this oppressive weather is at higher elevations, where temperatures are cooler. Eighty-five percent or more of the average annual rainfall accumulates during this season. In the north, the southwest monsoon is not well established until early June, but as the NETWC begins to move northward during April, the south experiences less and less of the dry conditions associated with the northeast monsoon.

During the April-May transition, before southwesterly flow becomes firmly established, local winds, land and sea breezes, and mountain and valley winds dominate the circulation. The area's highest temperatures occur early in the season, before the cloud cover reaches its maximum.

Sky Cover. Cloudiness begins to increase during the first part of the season as the NETWC moves northward during April and May. By July, the southwest monsoon is firmly established, and cloudiness is at its maximum for the season. The percent frequency of ceilings increases from 30-50 percent in April to more than 70 percent in July (see Figure 5-14). A notable exception occurs at Sattahip, separated from peninsular Thailand by only 60 miles across the Bight of Bangkok. Sattahip apparently experiences lee-side effects due to its proximity to the peninsula, leading to infrequent ceilings during the southwest monsoon. Another possible factor contributing to this phenomenon is Sattahip's location northeast of an extension of land jutting into the Gulf of Thailand. This peninsula may also shield Sattahip somewhat from the southwesterly flow.

Morning fog causes ceilings to drop below 3,000 feet as often as 60 percent of the time near the northern coast and in the mountains. Afternoon ceilings less than 3,000 feet occur at many locations 50 percent of the time or more due to the moist southwesterly flow, orographic lifting, and convection (see Figure 5-15). As the southwest monsoon retreats southward at the end of the season, cloudiness decreases in the north.

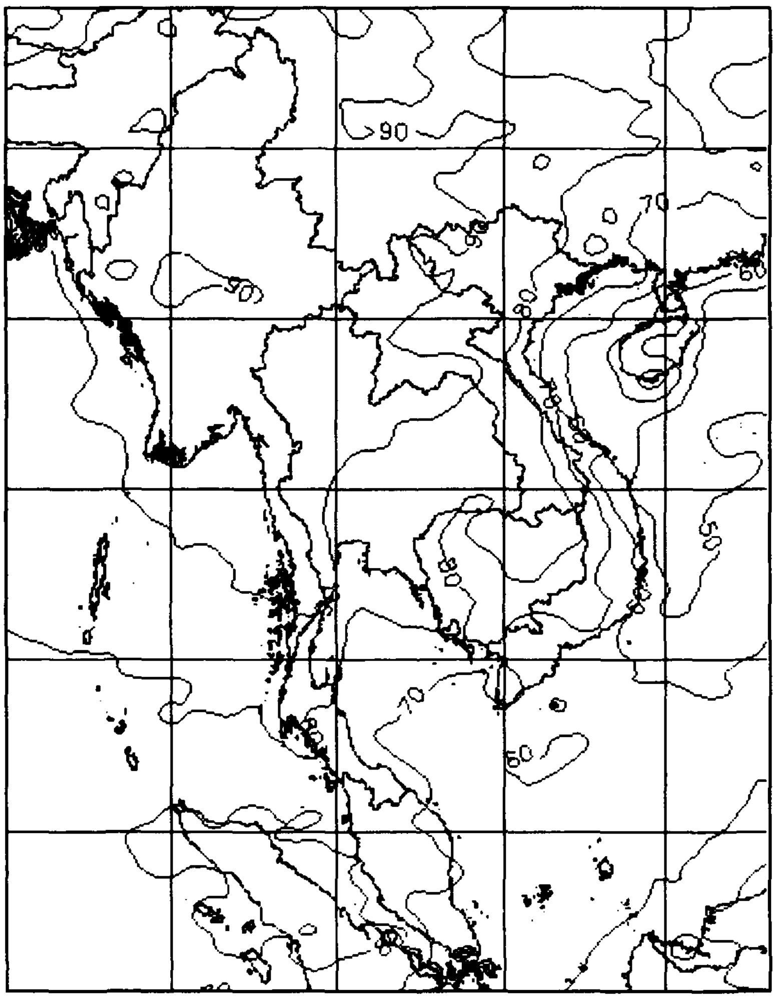


Figure 5-14. July 00Z Ceilings. Figure shows percent frequency of ceilings at all levels.

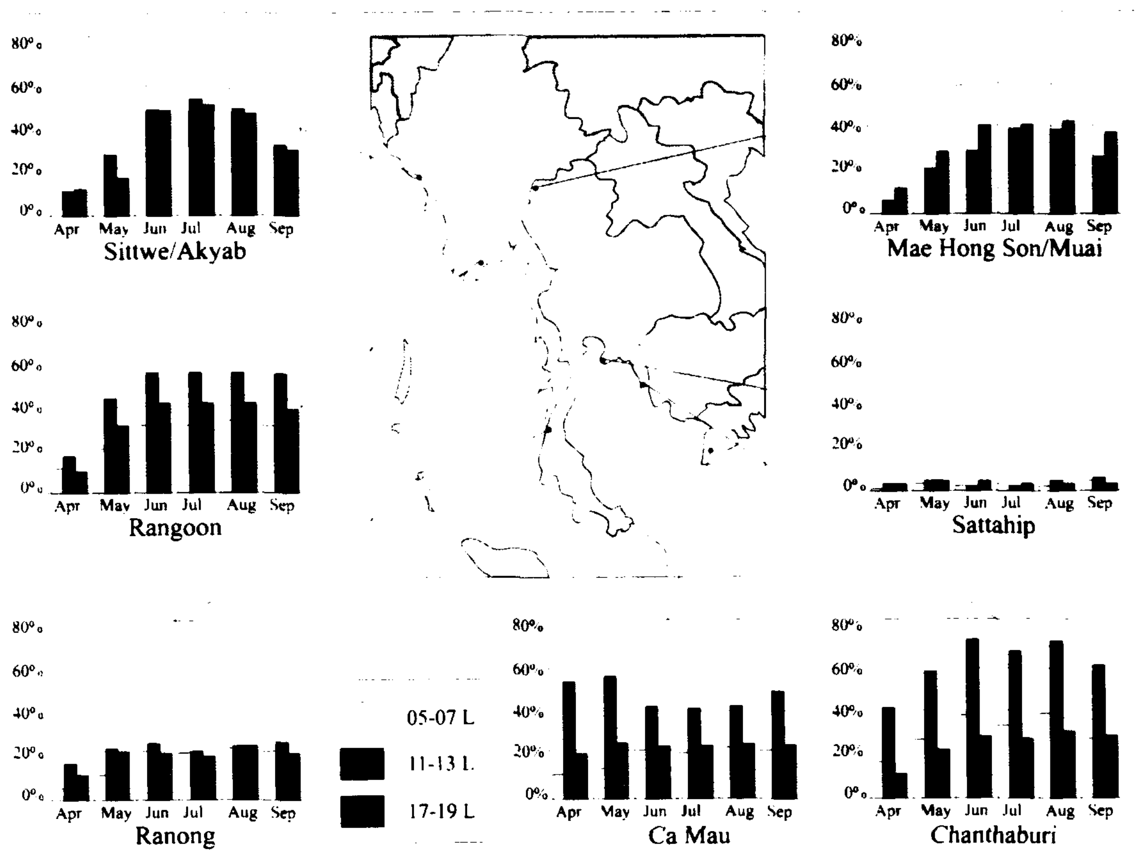


Figure 5-15. Southwest Monsoon Ceilings below 3,000 Feet. The graphs show a monthly breakdown of the percentage of ceilings below 3,000 feet based on location and diurnal influences.

Visibility. Early in the season, fog, haze, and smoke restrict visibility. Fog usually forms before dawn and, except in deep valleys, dissipates by 0900L; smoke is from burning fields. Conditions continue to improve with the onset of the southwest monsoon, although visibility rarely exceeds 16 km near the surface. Except in rainfall, afternoon visibility is generally 8-11 km, when it averages 3,200-4,800 meters; heavy rainfall can restrict visibility to 1,600 meters or less. The highest frequency of visibility less than 4,800 meters (30-45 percent) occurs as a result of morning rain and fog along the northern coasts. Elsewhere, visibility less than 4,800 meters occurs less than 30 percent of the time (see Figure 5-16).

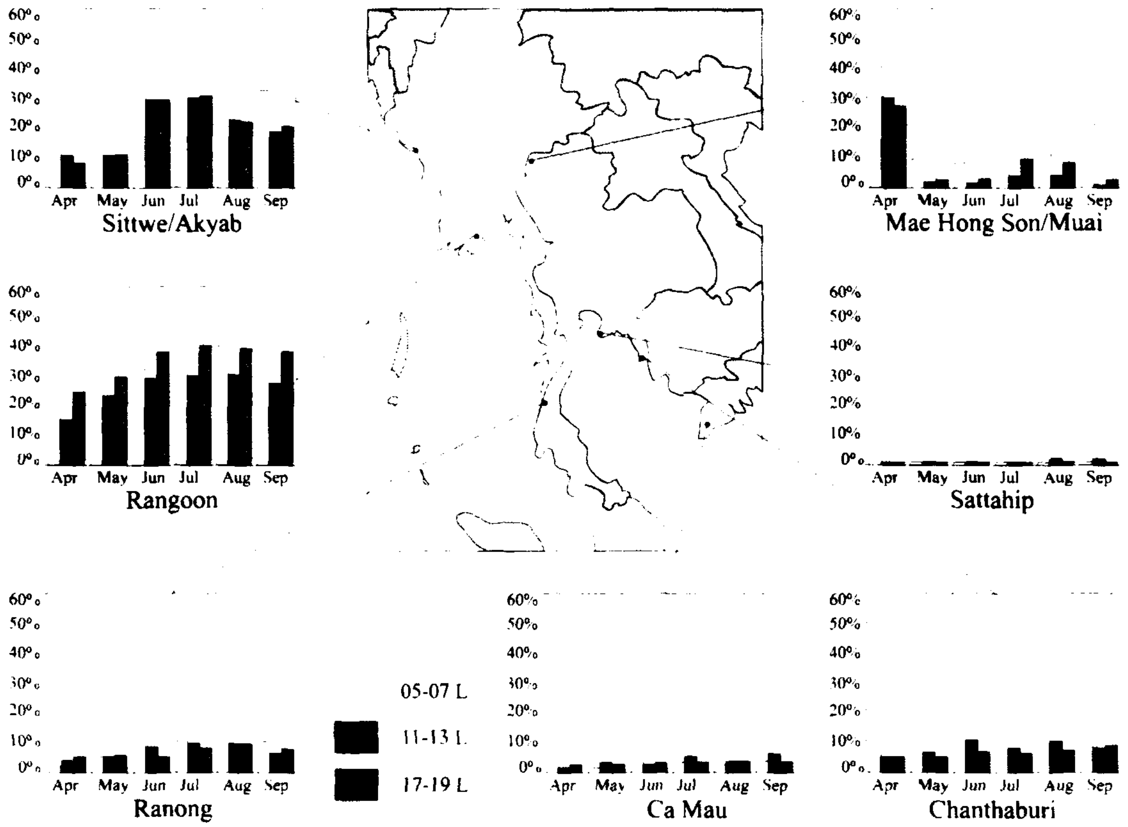


Figure 5-16. Southwest Monsoon Visibility below 3 Miles (4,800 Meters). The graphs show a monthly breakdown of the percentage of visibility below 3 miles (4,800 meters) based on location and diurnal influences.

Surface Winds. Land/sea breezes are strongest this time of year, especially during the intermonsoon period prior to the onset of the southwest monsoon. The diurnal land/sea breeze prevails along the coasts, where the sea breeze extends to 900 meters on the adjacent slopes. Figures 5-17 and 5-18 show several locations with a high percentage of calm winds during April and July, occurring mainly from night to early morning. The northwest has the fewest calm winds. By June, when the southwest monsoon is firmly established, surface winds are predominantly southwesterly at 5-10 knots. Near mountain ridges, winds average 15-25 knots.

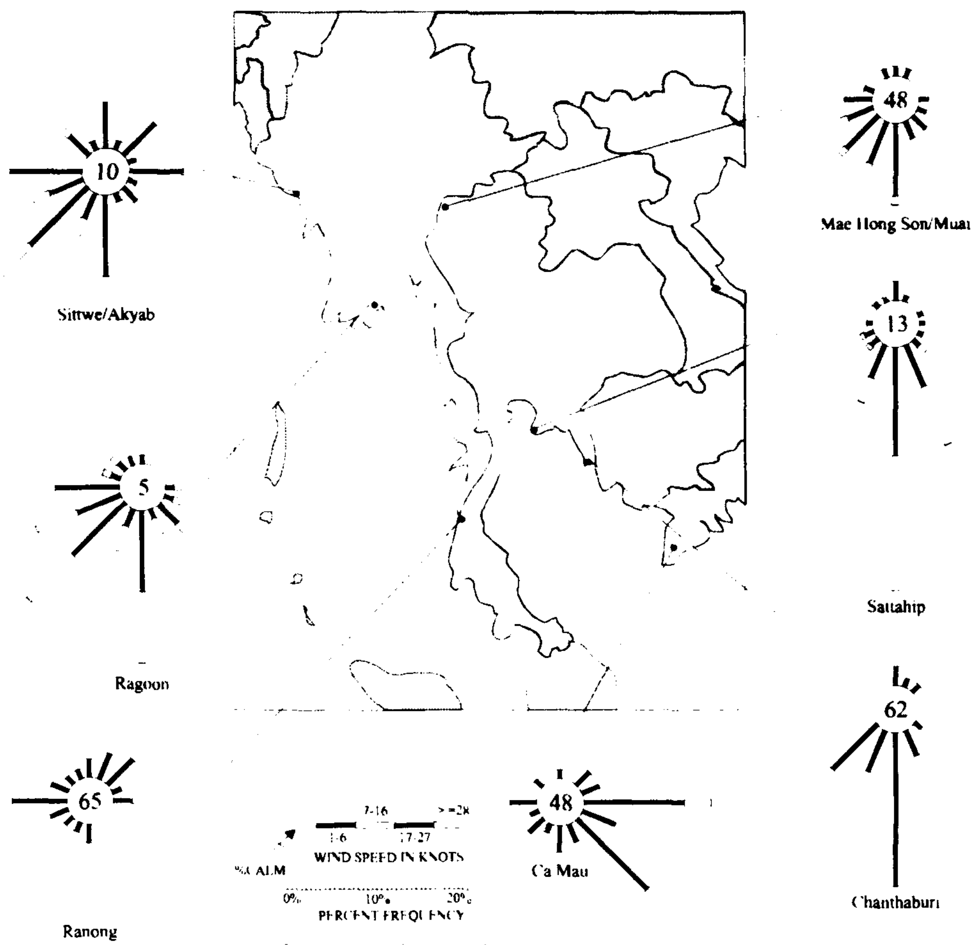


Figure 5-17. April Surface Wind Roses. The wind roses show the prevailing wind direction and range of speeds based on time, frequency, and location.

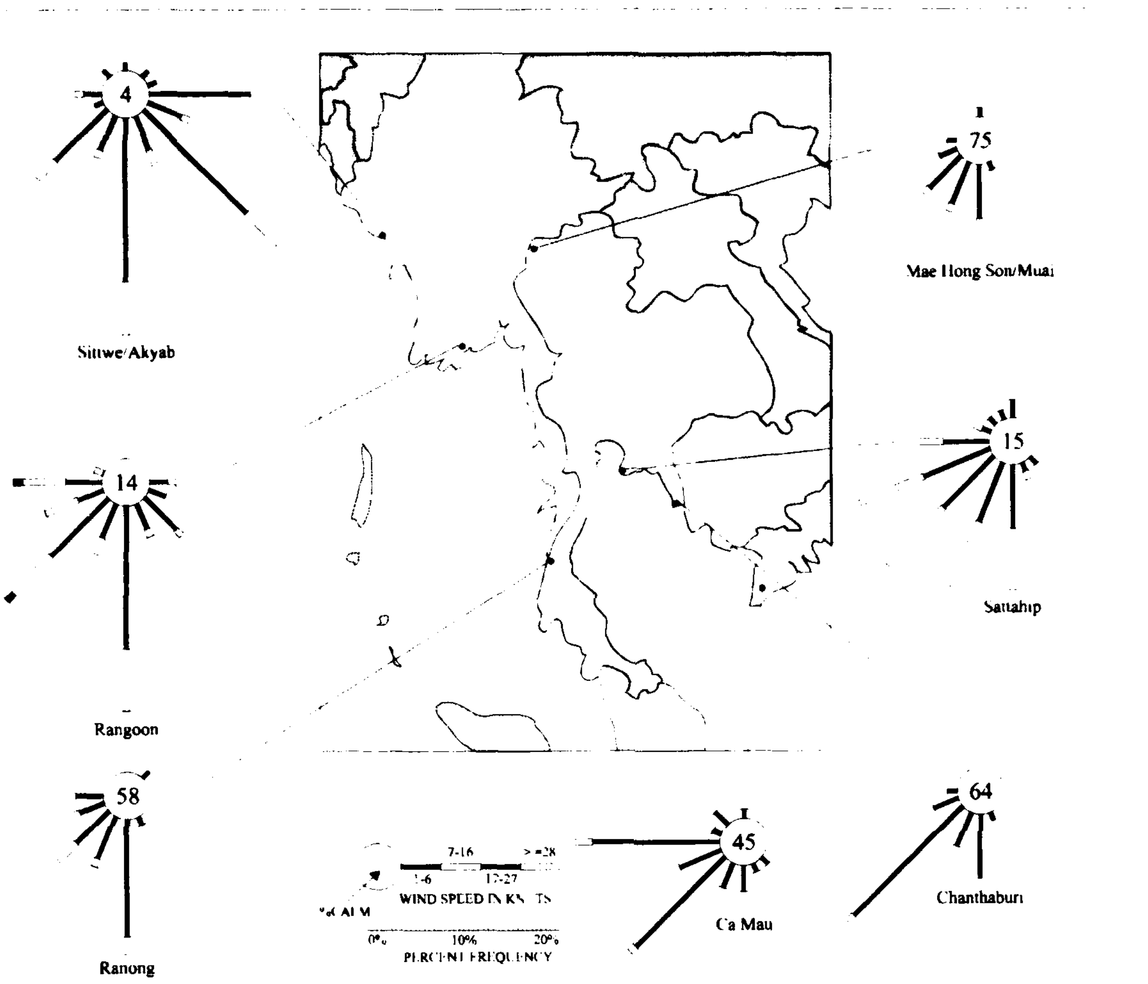


Figure 5-18. July Surface Wind Roses. The wind roses show the prevailing wind direction and range of speeds based on time, frequency, and location.

Upper-Level Winds. Early in the season, when the general circulation pattern is weak, upper-air winds are also variable and weak. April winds for Chanthaburi, Thailand, (see Figure 5-19) are predominantly southerly at low levels and easterly at about 3,000 meters, but at higher levels, winds are quite variable. Once the southwest monsoon is firmly established, westerlies prevail up to 3 km. At 5 km, winds are variable, but at about 8 km, easterlies predominate. At about 15 km, the tropical easterly jet (TEJ) fluctuates between 10° and 25° N. During April and May, the core speed of the TEJ is 50-75 knots; by June, it increases to 75-100 knots.

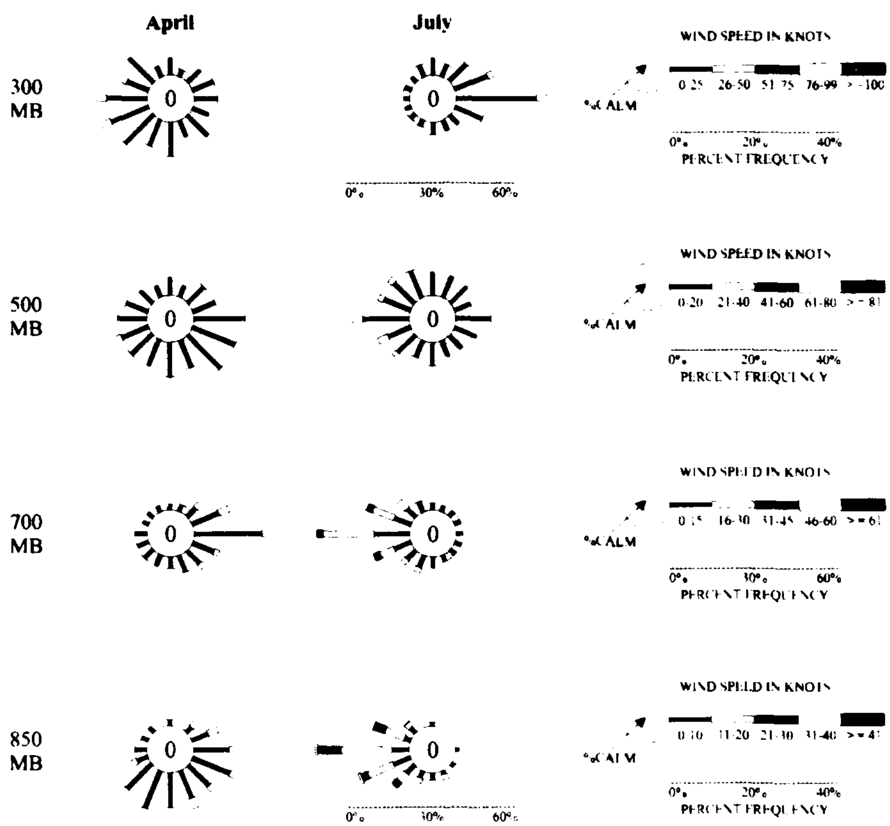


Figure 5-19. April and July Upper-Air Wind Roses. The wind roses depict wind speeds and directions for standard pressure surfaces between 850 and 300 mb at Chanthaburi, Thailand. Note: Each wind rose has a tailored legend. Wind roses with different percent frequency scales are marked accordingly.

Precipitation. Heavy rainfall, caused by cyclonic disturbances, convection, and orographic lifting make this the wettest time of year. Cyclonic disturbances occur primarily north of 10° N, while convection is most prominent south of 10° N. Orographic lifting increases rainfall amounts along the windward mountain slopes. The sea breeze is strongest during this season, and it strengthens the southwest monsoonal flow onshore during the day. This in turn enhances orographic lifting of the moist, unstable air and increases rainfall. For example, Akyab averages 1,400 mm during July, when the sea breeze is strongest, but it can receive over 2,000 mm. July rainfall is typical of the rest of the southwest monsoon. July average rainfall decreases inland from the western coasts and varies from more than 1,000 mm to 100-200 mm at some inland locations (see Figure 5-20).

The number of days with rainfall increases from the April-May intermonsoon period to July-August, when the southwest monsoon is at its peak. Rainfall days increase along the west coast from 5-10 in April to 22-28 in August. The northeast coast of the Gulf of Thailand has slightly fewer rainfall days during July-August with 15-22 days.

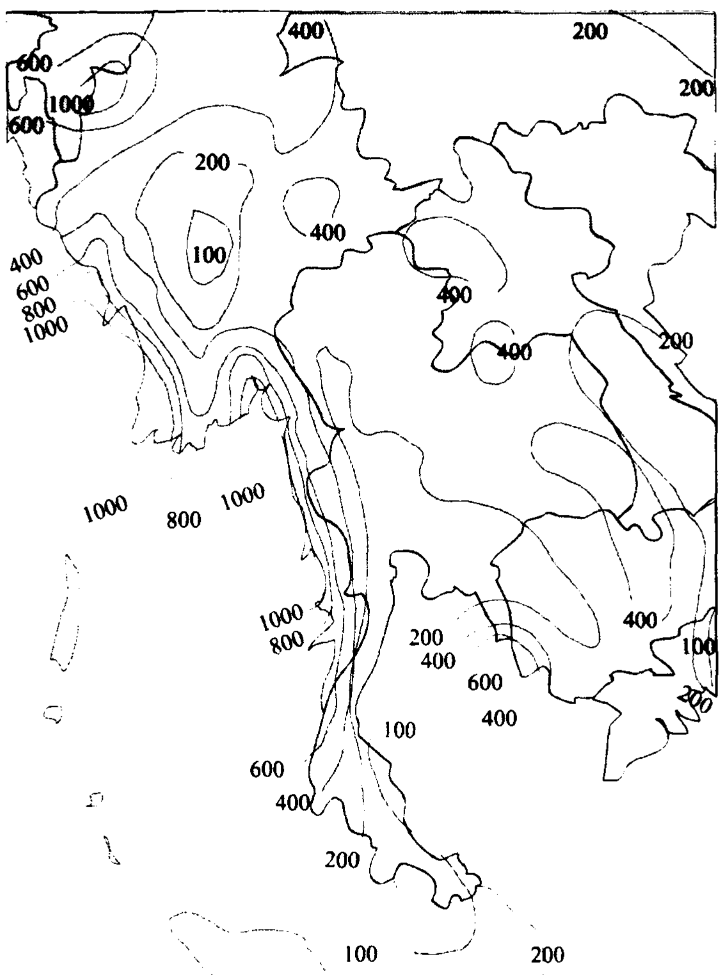


Figure 5-20. July Mean Precipitation (mm). Figure shows the relationship between onshore flow and orographic influences on precipitation amounts.

Thunderstorms. Although they occur throughout the area, thunderstorms are most frequent just before the onset of the southwest monsoon. May has the most thunderstorm days, averaging 10-15 in the south and 5-12 in the northwest (see Figure 5-21). The storms are embedded in the multilayered clouds of the southwest monsoon and reach 40,000-50,000 feet, with isolated tops up to 60,000 feet. Once the southwest monsoon begins, increased cloud cover reduces surface heating, thus thunderstorms become less frequent. In July, most locations average 5-10 days with thunderstorms, but the northwest usually has fewer than 5 days with thunderstorms. During September, as the southwest monsoon retreats southward, thunderstorm frequencies increase again.

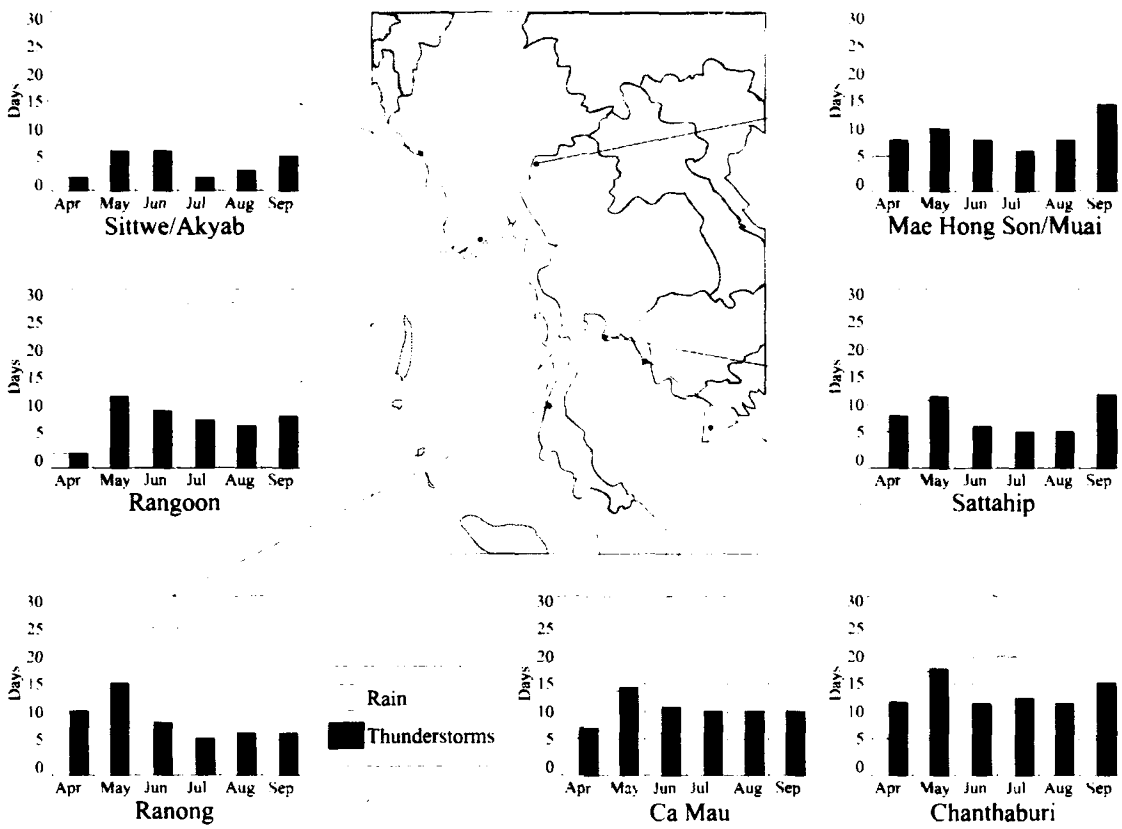


Figure 5-21. Southwest Monsoon Monthly Rain and Thunderstorm Days. The graphs show the number of days with rain and thunderstorms based on monthly averages at scattered locations within the west-facing coasts.

Temperatures. April temperatures are the highest of the season due to decreasing cloudiness and increasing insolation. Average highs exceed 30°C nearly everywhere. It is warmest in the lowlands near the coasts, where average high temperatures in April reach 37°C. In the southern plains of Myanmar, April highs can exceed 40°C; Rangoon's temperature has reached 41°C in April. As the southwest monsoon moves northward, cloudiness increases and temperatures fall. By July, average highs range from 26° to 30°C (see Figure 5-22) with extreme highs reaching 35°-37°C in the coastal lowlands. The southwest monsoon's high temperatures and high relative humidities combine to produce mean maximum wet-bulb globe temperatures of 30°-32°C throughout the region.

Early in the season, low temperatures in northwestern mountain valleys can drop to 7°C. Elsewhere, April extreme lows reach 15-20°C. Average lows are around 21°-25°C in July (see Figure 5-23).

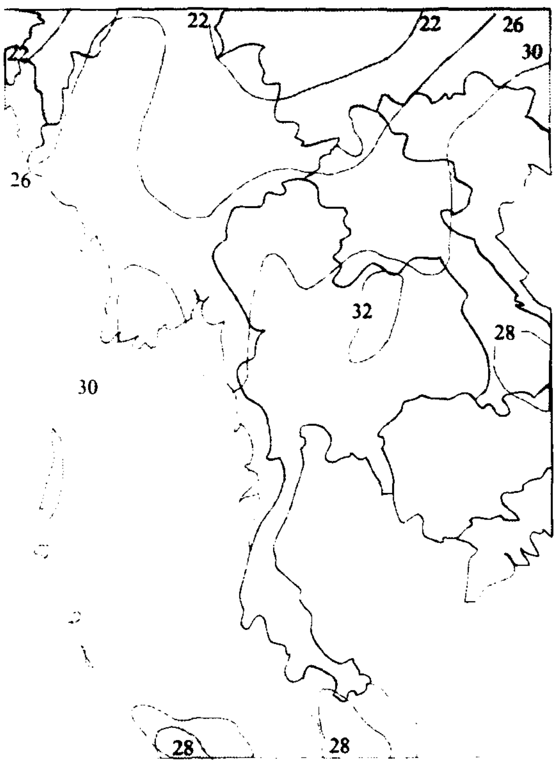


Figure 5-22. July Mean Maximum Temperatures (°C). Isopleths represent the average of all high temperatures during the most representative month of the northeast monsoon.

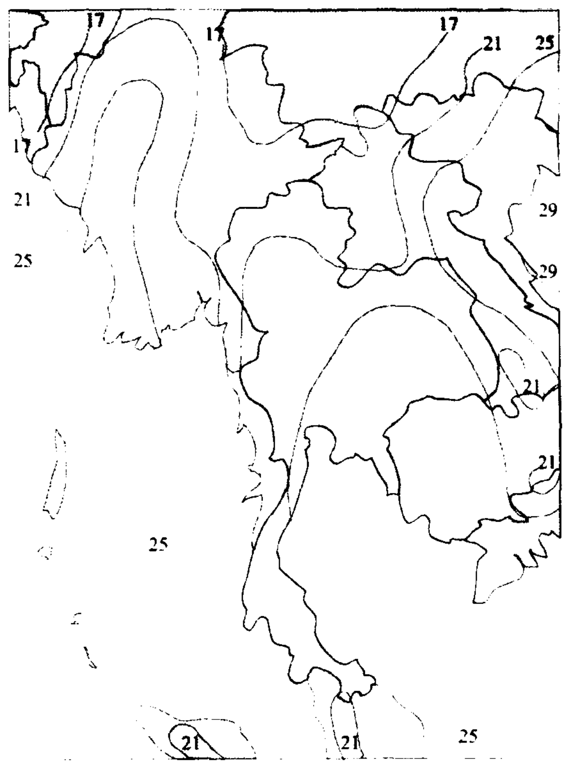


Figure 5-23. July Mean Minimum Temperatures (°C). Isopleths represent the average of all low temperatures during the most representative month of the northeast monsoon.

Other Hazards.

Turbulence. Turbulence is possible on the lee side of mountain ranges in this climatic zone and in the vicinity of the TEJ.

Tornadoes. Tornadoes are possible throughout the season, but they are most probable during the intermonsoonal transition period of April-May. While not as intense as the midwestern United States variety, they do cause loss of property and occasionally loss of life. Tornadoes often form as waterspouts that move onshore and are often associated with typhoons. The areas of this climatic zone where tornadoes are most likely are southern Vietnam, the Ca Mau Peninsula, and the lowlands of Thailand.

Floods. Southern Vietnam and southeastern Cambodia are especially susceptible to flooding during the southwest monsoon because of their low elevation. This area is also prone to torrential rains from typhoons.

Trafficability. Trafficability is at its worst during the southwest monsoon. No part of this climatic zone has better than fair to poor trafficability, due to the soil, terrain, and the southwest monsoon's heavy rainfall. The lowlands and river deltas of southern Vietnam have the worst trafficability—poor to impossible. This area is flooded for long periods. When the area is not flooded, it has poor to impossible trafficability due to its fine-grained soils. Southwestern Cambodia and southeastern Thailand have mixed fine- and coarse-grained soils, which generally have fair to poor trafficability when wet. The heavy rainfall, rugged terrain, and mixed fine- and coarse-grained soil of peninsular Thailand and the Tenasserim coast combine to produce poor trafficability. The Arakan coast also has fine- and coarse-grained soils, but it has less rainfall. Consequently, trafficability is generally poor, but occasionally fair.

Chapter 6

CENTRAL SOUTHEAST ASIA

This chapter describes the geography, major climatic controls, special climatic features, and general weather (by season) for central southeast Asia, as shown below.

Central Southeast Asia

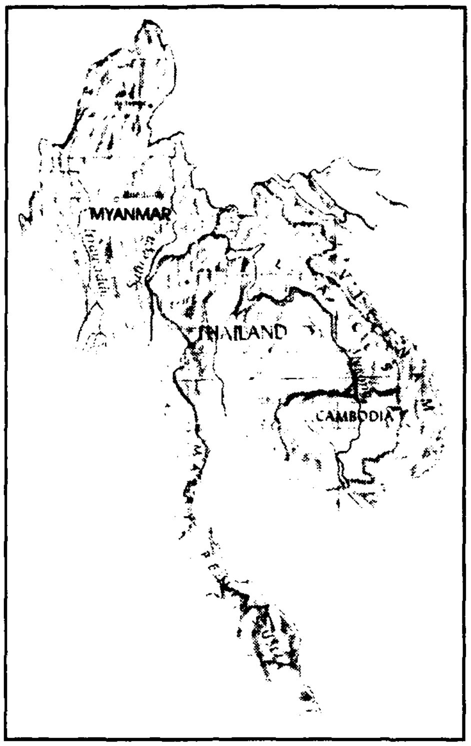


Figure 6-1. Topography. This map shows major place names, rivers, and terrain features.

Boundaries. This region encompasses the eastern corner of Myanmar, nearly all of Laos, Thailand (excluding northwestern, southeastern, peninsular Thailand), central and eastern Cambodia, and southern Vietnam (excluding the Ca Mau Peninsula and the Mekong River Delta).

Topography. The eastern corner of Myanmar is bordered by Thailand and Laos on the southeast and China on the northeast (see Figure 6-1). The rugged Tenasserim Mountains generally run north-south, but near Lashio the range assumes a northeast-southwest orientation. Peaks reach 2,563 meters near the border with Laos and 2,300 meters west of Lashio.

Laos encompasses more than 236,000 square km (slightly smaller than Oregon). The terrain is generally composed of rugged mountains with a few sloping plains in the south. Laos also contains a high plain region cut by deep river valleys. The mountain ranges are oriented northeast-southwest, with many peaks extending above 2,100 meters; 95 km northeast of Vientiane stands Phou Bia, the highest point (2,817 meters). Southeastern Laos contains the Annam range, which runs along the Vietnam border. Central Laos contains the "Plain of Jars," an area of gently undulating plains, sloping toward the Mekong River valley floor. This area bears that name because of the thousands of huge buried jars strewn over the plain.

Approximately 430,000 square km of Thailand lie within central southeast Asia. Four important geographical features occupy this portion of Thailand: the northern mountains, the lowlands, the Korat plateau, and the western mountains. The rugged northern mountain region is composed of primarily north-south oriented hills and mountains cut by long, narrow valleys. Much of the northern terrain rises above 900 meters, with several peaks above 1,500 meters. The highest peak, Doi Angka, 56 km west-southwest

of Chiangmai, rises to 2,580 meters. The extensive Chao Phraya lowlands, with elevations generally below 90 meters, cover most of central Thailand. They extend north from the Gulf of Thailand about 1,150 km. The Phetchabun Mountains runs north-south through the center of Thailand and separates the Chao Phraya lowlands from the Korat Plateau, a broad, flat area with elevations generally below 200 meters. A river system flowing southeastward into the Mekong River along the Laos border drains the plateau. The Dawna Range, which extend along the western border with Myanmar, is about 560 km long and 80 km wide.

Cambodia covers 181,000 square km (about the size of Missouri); about three-fourths of th country is included in central southeast As Cambodia has three major geographical features within this region: the Mekong River, which flows through the eastern half of the country; the Tonle Sap, a large, shallow lake surrounded by gently undulating plains in the western half of the country; and the Dangrek Range in the north. With elevations generally near 300 meters, spurs of the Annam Range along the Vietnam border extend into Cambodia. Southwest of the Tonle Sap Lake, beyond the plains, a low, broken plateau is backed by higher plateaus and mountains with peaks between 900 and 1,500 meters.

Southern Vietnam stretches in an arc from the Mekong River delta northeast to about Nha Trang on the China Sea coast, and north to the intersection of the borders of Laos, Cambodia, and Vietnam. Extensions of the Annam Mountains occupy the northern section, with plateau heights varying from 180 to 300 meters AGL. Peaks in the center of the area reach 2,400 meters, but farther south, the highlands give way to plains and lowlands, terminating in the Mekong delta. The delta is composed of elevations below 50 meters and is a major rice producing area because of its extensive series of levies.

Rivers and Drainage Systems. The Mekong River is the primary drainage system for the rugged terrain and sloping plains of Laos. After forming the Laos-Myanmar border and a small portion of the Laos-Thailand border, the Mekong meanders roughly southward through western Laos. It again forms the border with Thailand beginning about 120 km west of Vientiane and continuing southeastward to about 160 km north of the point where Laos, Thailand, and Cambodia meet. Before entering Cambodia, the Mekong flows through the extreme southern portion of Laos for approximately 240 km. Inside Cambodia, the Mekong traverses the eastern third of the country from north to south. After flowing into Vietnam, the Mekong turns to the theast and begins forming its vast delta, posed of sand dunes, marshlands, and shallow lagoons). The low-lying swamps and marshlands expand during the wet season and dry out slightly during the dry season. (For a detailed discussion of the Mekong R: er, including its delta, see West Facing Coasts, Chapter 5).

The central plains of Cambodia are drained by the Tonle Sap (Great Lake) and the Mekong and Bassac rivers. Several relatively long rivers flow across the plains and drain into the Tonle Sap, and there are numerous small lakes and marshes east of the Mekong. A large man-made water reservoir, Nam Ngum, is south of the Plain of Jars region in Laos. The Chao Phrayal Lowlands of central Thailand are drained by several rivers that merge near Nakhon Sawan. The merging rivers then become the Chao Phraya River, which drains into the Gulf of Thailand. Most of the smaller rivers in eastern Myanmar empty into the Salween, which drains the eastern half of the area, or the Irrawaddy, which lies to the west. Both of these major rivers eventually empty into the Andaman Sea.

Vegetation. Heavy forests are found away from Cambodia's rivers and Tonle Sap Lake. Vietnam's rich and diverse vegetation includes evergreen and

deciduous forests and numerous species of woody vines and herbaceous plants. Mangrove forests thrive in the coastal swamps, while brushwood, bamboo, weeds, and tall grasses invade cleared forests and grow around settlements and line highways and railroads. Cogon grass is commonly found in the open forests, and grass savannas occupy large areas formerly covered by forests. The defoliants used during the Vietnam War have affected large amounts of Vietnam's vegetation, especially coastal mangrove forests and inland forests.

Myanmar's highlands are covered with a red "laterite" soil; while protected by the forest cover, it absorbs heavy rain, but once the forest is cleared, this soil erodes quickly. Cambodia contains about 12 million acres of unforested land; all are arable with irrigation, but less than half this land is cultivated. Some rice, corn, sugar, and wheat is grown here, and a small amount of rubber is still produced from rubber trees. The transitional plains are composed primarily of savanna, with 5-foot (1.6-meter) high grass in places; the high plateaus of the eastern highlands are covered with deciduous forest and grassland. Cambodia's northern mountains contain evergreen forests with trees 30 meters high growing from the thick underbrush. This regime continues into southern Laos, where forests of mixed evergreens and deciduous trees are found. In the north, broadleaf evergreens abound.

The climate of central southeast Asia is controlled by the monsoonal circulation, which is driven by the high- and low-pressure centers of Asia, the North Pacific, Australia, and the Indian Ocean. From September to March, the northeast monsoonal flow originates from the cold Asiatic (Siberian) and the warm North Pacific highs. The air flows from these highs toward the Near Equatorial Tradewind Convergence (NETWC), which is south of central southeast Asia during this season. The high terrain of the Tibetan Plateau blocks much of the direct flow of cold air from the Asiatic high, but cold air does channel into the northern part of the region through mountain passes. Traversing mainland China, the South China Sea, and the Pacific Ocean, the monsoonal flow gains warmth and moisture in the lower levels. The northeast monsoonal flow is usually most pronounced in January, when the Asiatic high is at its maximum intensity.

The southwest monsoonal flow results from the dynamic balance between the semipermanent highs over Australia and the Indian Ocean highs and the semipermanent Asiatic low. The air originating over Australia is warm, stable, and very dry, but it is rapidly modified as it passes over the equatorial waters. By the time it merges with flow from the Indian Ocean over Sumatra and Malaya, this air is very moist and unstable in the lower layers. When the air mass arrives over central southeast Asia, it is fairly homogeneous, and the entire area experiences tropical maritime temperatures and humidities. Nevertheless, terrain plays a large part in varying temperature, moisture, winds, clouds, and precipitation. The southwest monsoon prevails from mid-May to late September but is strongest in July and August, when the Asiatic low reaches maximum development. The flow is strongest at 900 to 1,500 meters but may be traced up to 4,500 meters. In north central southeast Asia, the flow becomes more shallow late in the season, and in September the flow does not extend above 3,000 meters.

Fronts. True fronts typical of weather patterns in higher latitudes do not generally affect southeast Asia. During the northeast monsoon, however, remnants of fronts occasionally move over northern Laos, bringing some cloudiness but little precipitation. Surges of cold air from China can move southward from October to April.

Tornadoes. Although generally not as intense as similar storms in the United States, tornadoes are a threat to all of southeast Asia. Tornadoes have been reported year-round but are most prevalent during the spring transition. A particularly high number of tornadoes occur along the coast of Thailand's Chao Phraya Lowlands.

Winds of Laos. These foehn (downslope) winds, most prevalent along the southern Vietnam coast north of Nha Trang, originate from the high plateaus of Laos and the Annam Range. As the air descends the eastern slopes, it becomes warmer and drier; the strongest of these winds can cause rapid temperature rises and extreme evaporation. The "Winds of Laos" occur mainly during the southwest monsoon, but they can occur during the transition seasons as well.

Typhoons. Since most of central southeast Asia consists of inland territory, the most devastating effects of typhoons on the area are minimal. Some areas are vulnerable to the high winds, storm surges, and high surf associated with typhoons. Elsewhere, typhoons winds are blunted by mountainous terrain, and storm surges have no affect on areas away from the coastline. Excessive rain, however, remains a serious hazard. Typhoons dump torrential rains over the entire region. These huge amounts of rain overwhelm the drainage system. Rivers, streams, and lakes burst their banks and cause wide-spread flooding. Flash floods in mountainous terrain are especially life-threatening. However, tropical storms have moved across northern Vietnam and into Laos before losing their strength, and the southern Vietnam coast is particularly susceptible to tropical storms and typhoons passing westward through the South China Sea. Most typhoon activity occurs from June through December, with the storms occasionally moving inland and sweeping through the center of the area before dissipating in central Thailand.

General Weather. September is a transition month, with the weather exhibiting features of both the southwest and northeast monsoons. The Asiatic low fades away as the landmass supporting it cools, and its opposite, the Asiatic high, begins to establish itself. This all occurs in September and October, with the transition completing by the end of October. During this transition, southwesterly flow weakens and shifts to northeasterly by late September or early October. Once the northeast monsoon is well-established, most cloudiness and precipitation occur on the windward slopes of the Annam Range and along coastal Vietnam. Most moisture does not pass over the Annam range, so the northeast monsoon is the dry season for most of central southeast Asia. Cool, dry air from the Asiatic high brings the area's lowest temperatures. Upper-level haze occurs near the temperature inversion at the top of the monsoonal flow, and strong subsidence greatly inhibits convection.

Late in the season, lows and troughs moving with the subtropical westerlies can affect the northern part of the area, causing scattered convective activity and increased clouds and rain, usually lasting 1-2 days. Early cold surges, which spill out of the intensifying Asiatic high, can occur as early as mid-October. These cold surges will trigger thunderstorms and rainshowers wherever the cold, dry air collides with warm, moist air.

Sky Cover. Other than early morning stratus decks, which frequently form along river valleys, ceiling occurrences are generally at a minimum during January (as shown in Figures 6-2 and 6-3). Ceilings below 1,000 feet occur, but they dissipate by late morning, and the region usually has clear to scattered skies from late morning through evening. Widely scattered cumulus may form in the afternoon, with bases between 1,500 and 3,000 feet and tops less than 8,000 feet; scattered cirrus is also common during the northeast monsoon. Occasional thunderstorms at the beginning and end of the season produce increased cloudiness most often over coastal areas. Early in the season, intermittent tropical waves produce increased cloud cover and an occasional mid-cloud ceiling.

The cold, dry air mass of the Asiatic high suppresses convective activity even as far south as this region; however, windward slopes, which face the moisture sources (oceans), are still vulnerable.

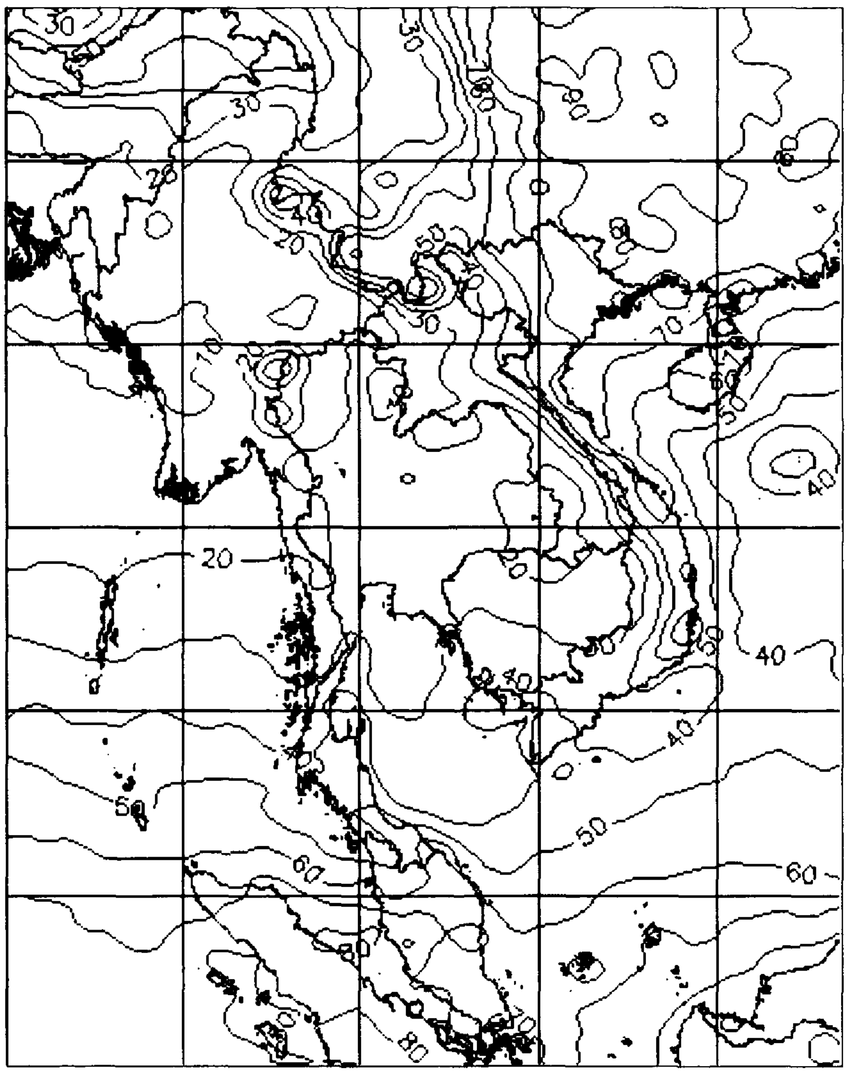


Figure 6-2. January 00Z Ceilings. These percentages represent the frequency of cloud ceilings at any altitude.

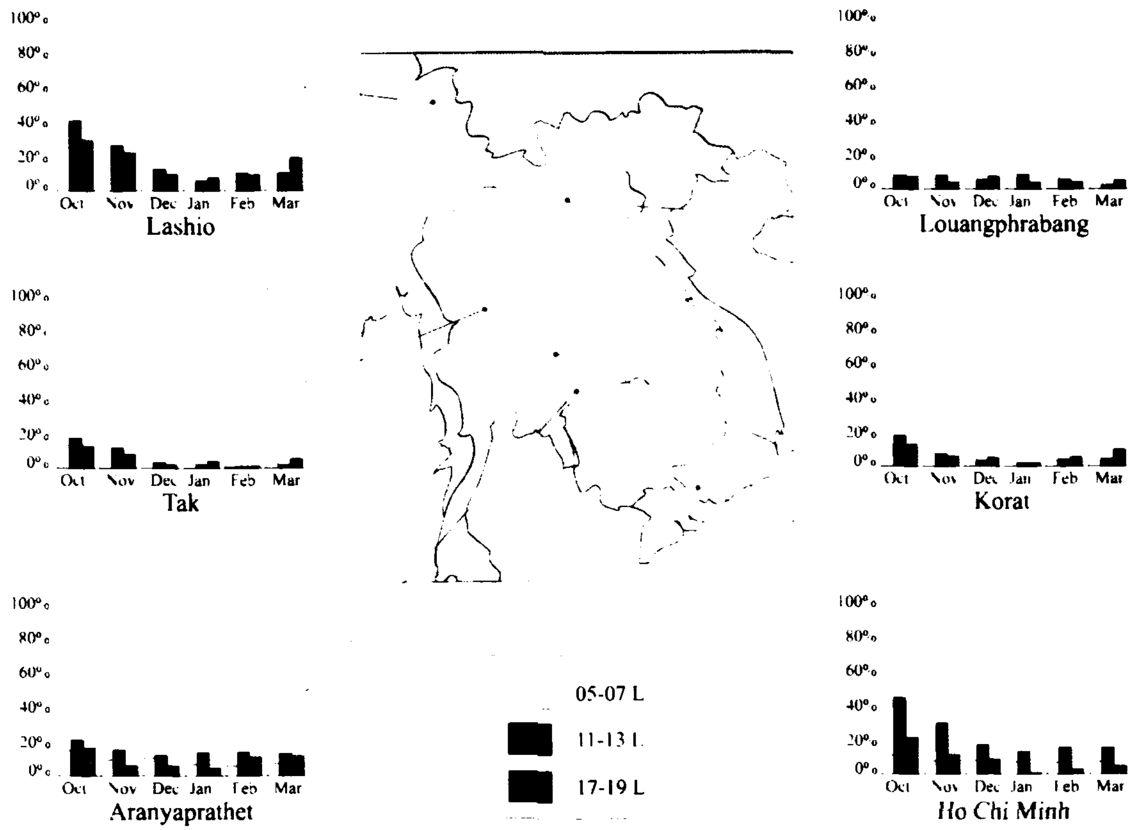


Figure 6-3. Northeast Monsoon Ceilings below 3,000 Feet. These graphs show the occurrence of ceilings based on location and diurnal influences.

Visibility. Fog, smoke, and haze are the major causes of reduced visibility during the northeast monsoon. Strong surges in the monsoonal flow can improve visibility by reducing the haze layer, but visibility greater than 16 km is generally uncommon over central southeast Asia. Early morning radiation fog occurs in highland areas such as Thailand's Korat Plateau, but it is most prevalent and persistent in deep, steep-walled valleys where visibility ranges from 0 to 3,200 meters nearly every morning. Radiation fog usually burns off by late morning, with visibility improving to more than 8,000 meters. As Figure 6-4 shows, fog less frequently restricts visibility after the morning hours. In protected areas, however, fog burns off later and reforms earlier. Visibility restrictions generally increase from south to north in central southeast Asia. Fog and low stratus are a problem in this season because of the strong inversion present with the northeast monsoon. This inversion caps valleys and other sheltered places and prevents mixing. Consequently, fog and stratus form.

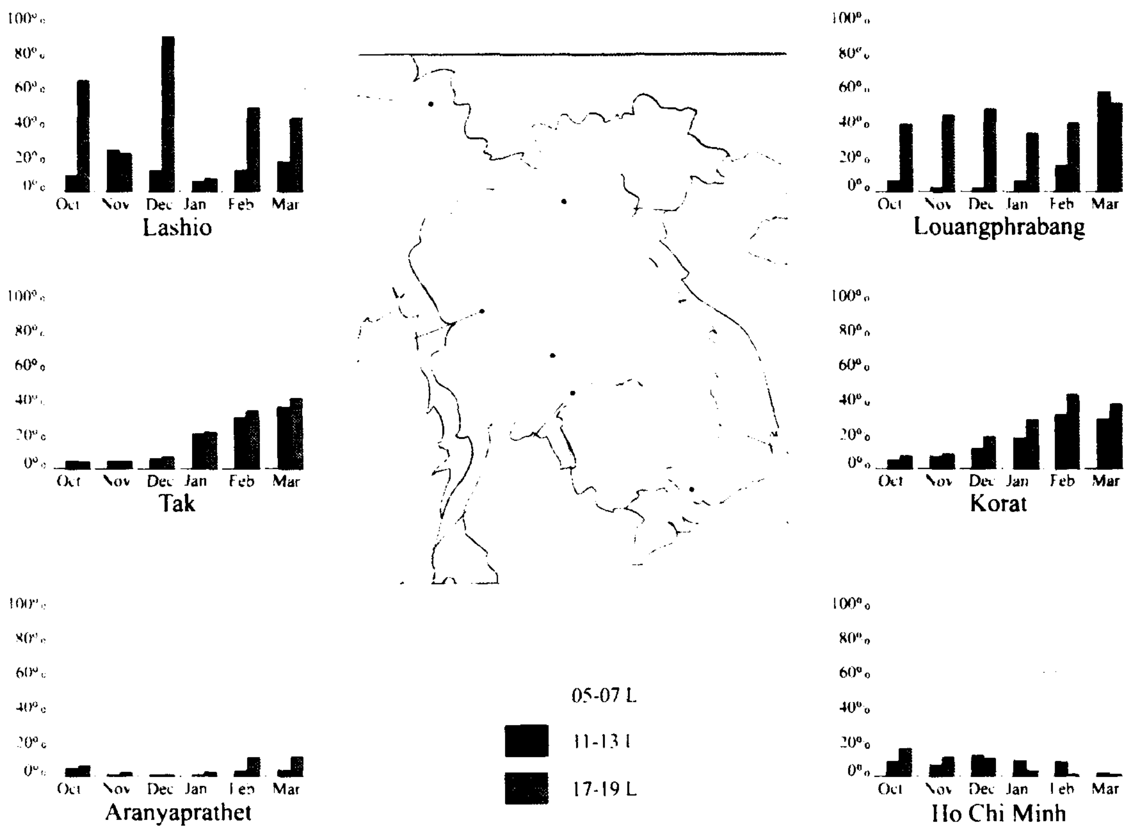


Figure 6-4. Northeast Monsoon Visibility below 3 Miles (4,800 Meters). The graphs show a monthly breakdown of the percentage of visibility below 4,800 meters based on location and diurnal influences.

Surface Winds. Surface winds are generally northerly to easterly at less than 10 knots, though the diverse terrain frequently causes variations from the monsoonal flow. The strongest winds (15-25 knots) are usually confined to coastal sections. Mountain and valley winds cause diurnal changes in direction and speed, and some coastal locations show variations due to land and sea breezes (note the winds for Ho Chi Minh City in Figures 6-5 and 6-6). For more information on these local effects, see the *Diurnal Wind* section in Chapter 2. Despite these variations, generalized northeasterly flow can be discerned throughout most of central southeast Asia. However, in the north the flow becomes less prominent, and wind speeds decrease. A nighttime inversion often causes calm winds over plateaus and low elevations. Figures 6-5 through 6-7 show January winds for 0600L, 1800L, and all hours, respectively.

Although generally too far south for foehn winds, some areas in the north get them in association with cold surges. Winds spill over the mountains and rush downslope. This usually happens after a frontal system has weakened the Asiatic high, and then it moves on. The high rebounds, intensifies, and sends cold air surging out. In this area, foehn winds are not extreme. Speeds of 25-40 knots are normal, and the foehn rarely lasts long.

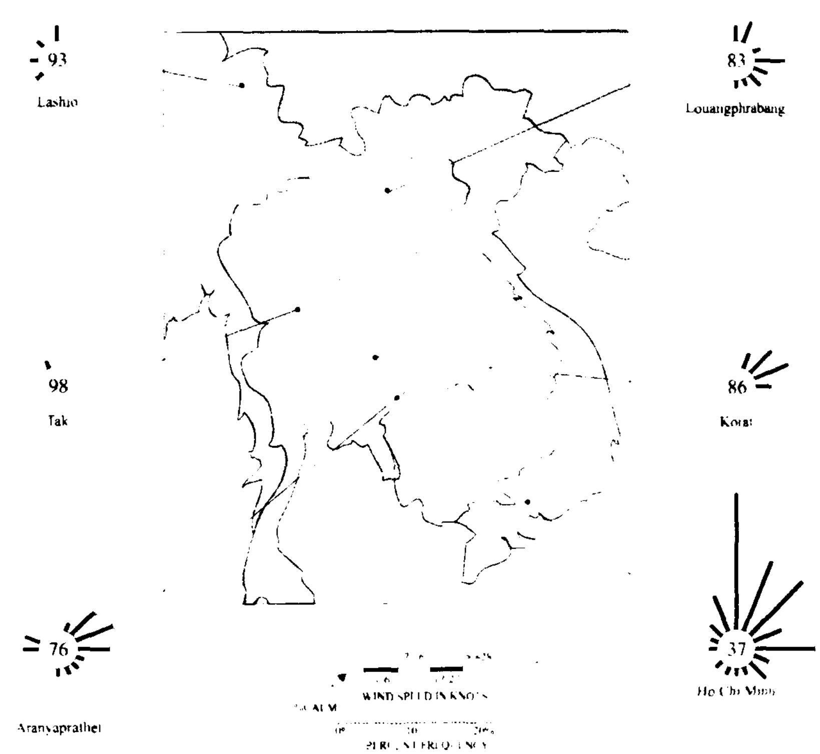


Figure 6-5. January 00Z (06L) Surface Wind Roses. The wind roses depict prevailing wind direction and range of speed for 00Z based on frequency and location.

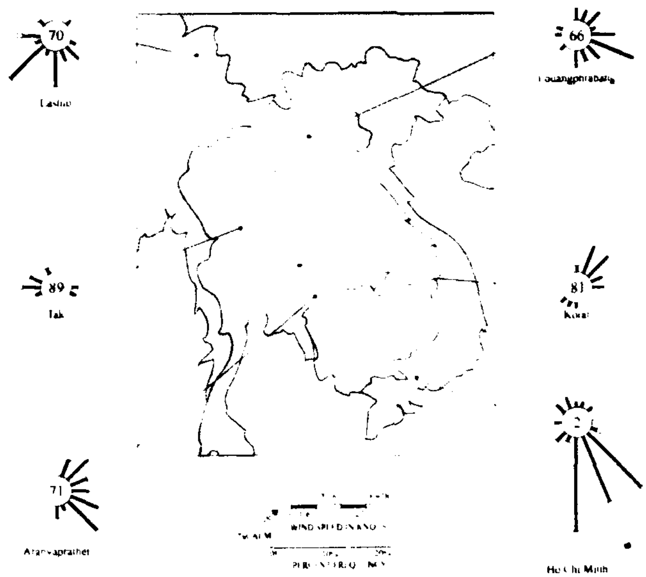


Figure 6-6. January 12Z (18L) Surface Wind Roses. The wind roses depict prevailing wind direction and range of speed for 12Z based on percent of frequency and location.

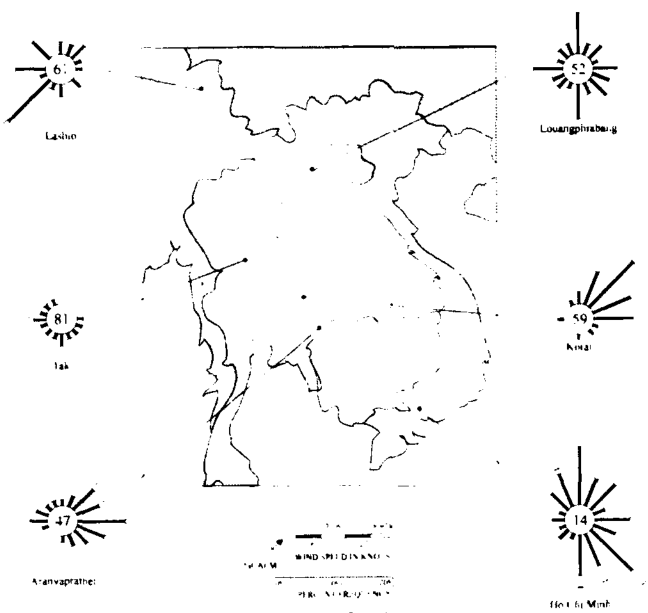


Figure 6-7. January Surface Wind Roses, all Hours. The wind roses depict prevailing wind direction and range of speed for all hours based on percent of frequency and location.

Upper-Level Winds. Up to 5,000 feet, winds are generally light and variable (5-10 knots) with an overall south or easterly component. Above that, they quickly shift to come from the southwest. By 10,000 feet, they are steady from the southwest at 10-15 knots. The direction remains the same through 50,000 feet, and the speeds remain well below 40 knots. The jet stream is north of the area and does not usually have a direct effect. Indirectly, it carries low-pressure systems into the area from the west.

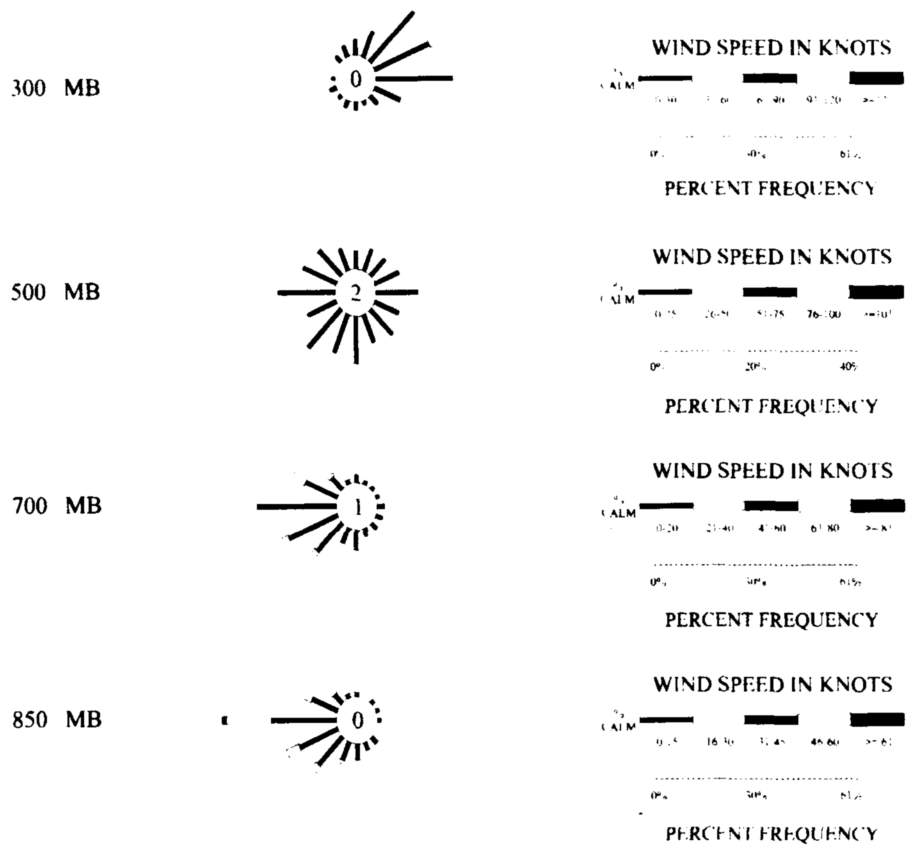


Figure 6-8. January Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 and 300 mb at Udonthani, Thailand. Note: Each wind rose has a tailored legend.

Precipitation. The Annam Mountains block much of the flow of moisture into central southeast Asia. This blocking, combined with strong subsidence from the Asiatic high, causes a general lack of precipitation during the northeast monsoon. The transition period into the northeast monsoon, however, brings frequent rainfall. A 24-hour precipitation maximum of 338 mm occurred at Chanthaburi, Thailand, in October, and northern Thailand and Laos have received more than 200 mm in 24 hours during November. Coastal areas receive the most precipitation during the transition, and they remain susceptible to tropical disturbances until the northeast monsoon is well-established in mid-December. As the Asiatic high reaches its maximum intensity in January, precipitation decreases throughout central southeast Asia (see Figures 6-9 through 6-11. Central southeast Asia receives an average of only 2 days of rain a month during the height of the northeast monsoon, and northern portions of the area have been rain-free from November to February in some years. In February, precipitation begins to increase slightly, but there is not a significant increase until the northern NETWC moves into the area (April-May). Cold surges produce convergence thunderstorm and rainshower lines. These move through quickly and drop relatively small amounts of rains as they pass.

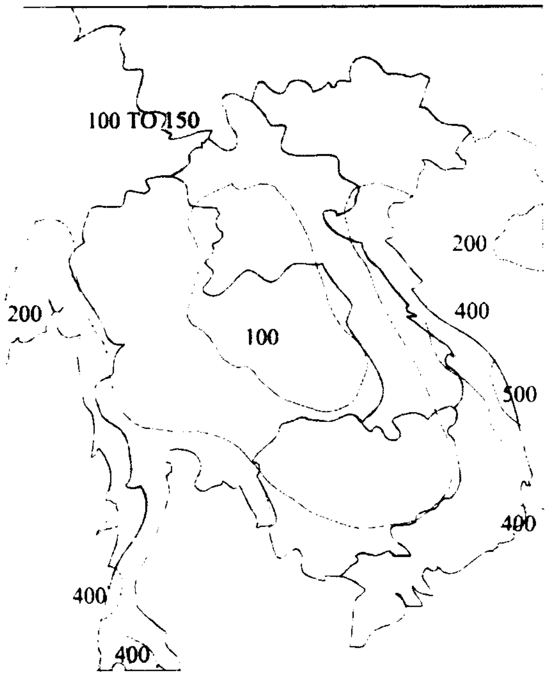


Figure 6-9. October Meam Precipitation (mm). The isopleths depict the amount of precipitation received at the beginning of the northeast monsoon season.

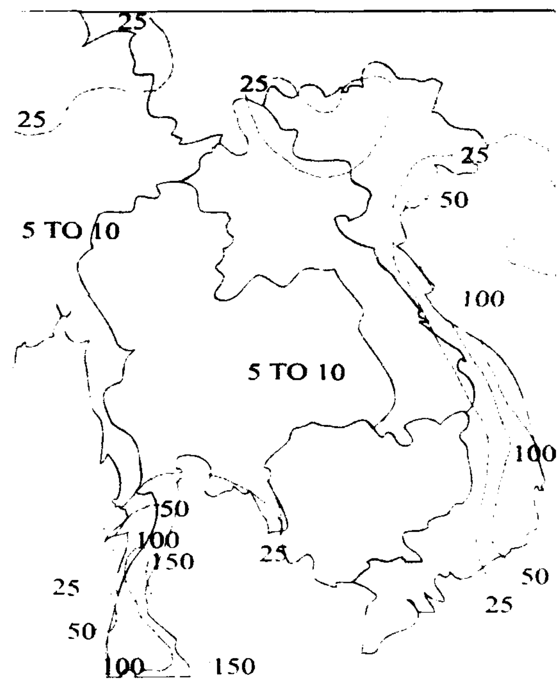


Figure 6-10. January Mean Precipitation (mm). The isopleths depict the amount of precipitation received in the middle of the northeast monsoon season.

Thunderstorms. Thunderstorm activity continues to decrease during the transition from the southwest to the northeast monsoon. Maximum thunderstorm activity during the northeast monsoon usually occurs in September when some southern coastal areas report 25 days with thunder. December through February can be thunderstorm-free for many locations, but central southeast Asia generally averages 2 days with thunderstorms during these months. When thunderstorms do occur, wind-blown dust and other contaminants tend to reduce visibility. Wind gusts from thunderstorms can exceed 50 knots, especially during the September transition. These speeds are most likely near the coasts. Thunderstorm tops can reach 60,000 feet; bases are relatively high, ranging from 2,000 to 4,000 feet, since most thunderstorms are formed orographically and the air is fairly dry. Cold surges early in the period produce most of the thunderstorm activity south of 15° N. As cool, dry, northerly air overrides the warm, moist air, extreme instability occurs and violent thunderstorms follow. These lines of storms move quickly and produce little rain. Tropical waves, which move through the area early in the season, also produce occasional thunderstorms.

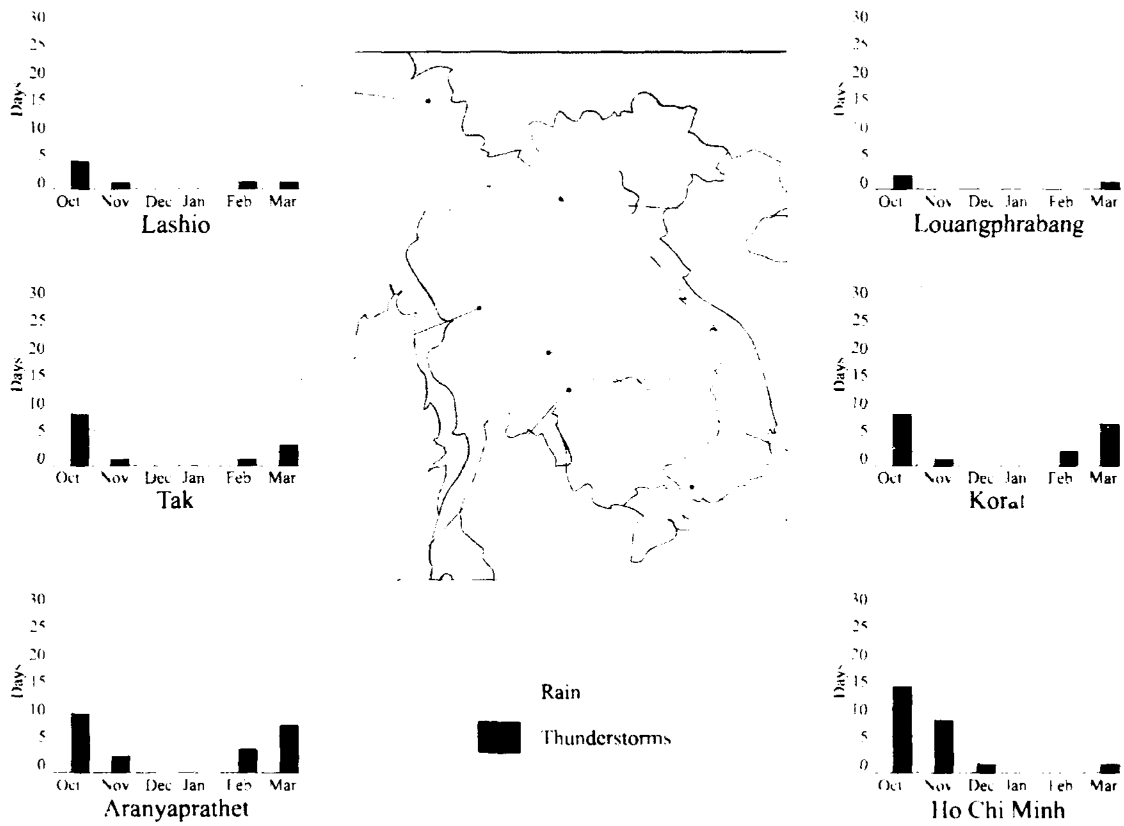


Figure 6-11. Northeast Monsoon Precipitation and Thunderstorm Days. The graphs show the average occurrence of rain and thunderstorm days for selected locations within central southeast Asia.

Temperatures. As the northeast monsoon strengthens, temperatures decrease throughout central southeast Asia. Northern sections experience the most dramatic temperature variations, and frost (although rare) does occur in the northern fringes when midlatitude disturbances affect the area. Extreme minimum temperatures range from -2°C in Lashio, Myanmar, to 14°C in Ho Chi Minh, Vietnam. Extreme maximums range from 30°C at Lashio in November to 42°C at Korat, Thailand, in March. Figures 6-12 through 6-15 show average temperatures across the region.

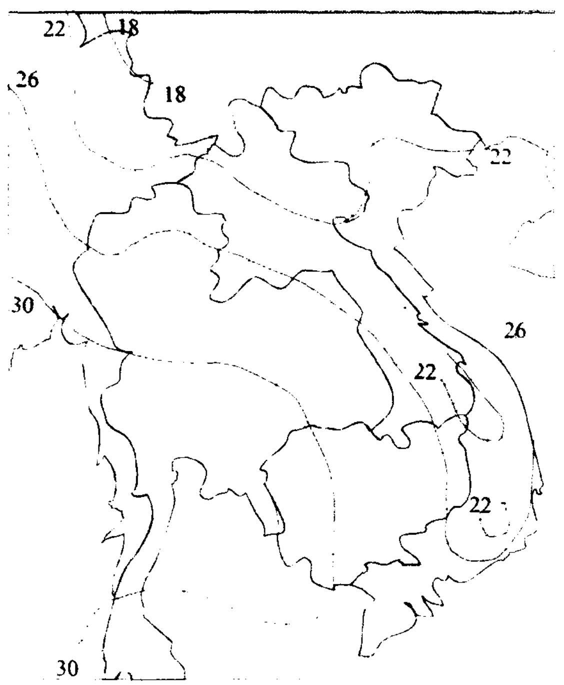


Figure 6-12. October Mean Maximum Temperatures (°C). The isopleths represent the average of all high temperatures during the early stages of the northeast monsoon.

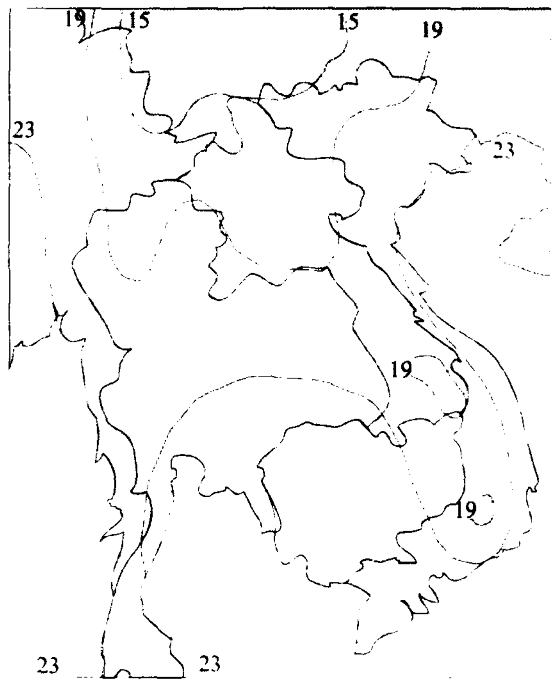


Figure 6-13. October Mean Minimum Temperatures (°C). The isopleths represent the average of all low temperatures during the early stages of the northeast monsoon.

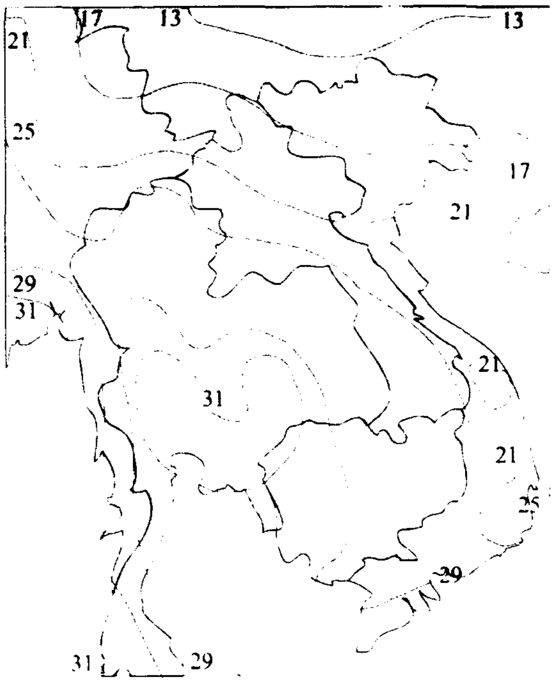


Figure 6-14. January Mean Maximum Temperatures (°C). The isopleths represent the average of all high temperatures during the middle stages of the northeast monsoon.

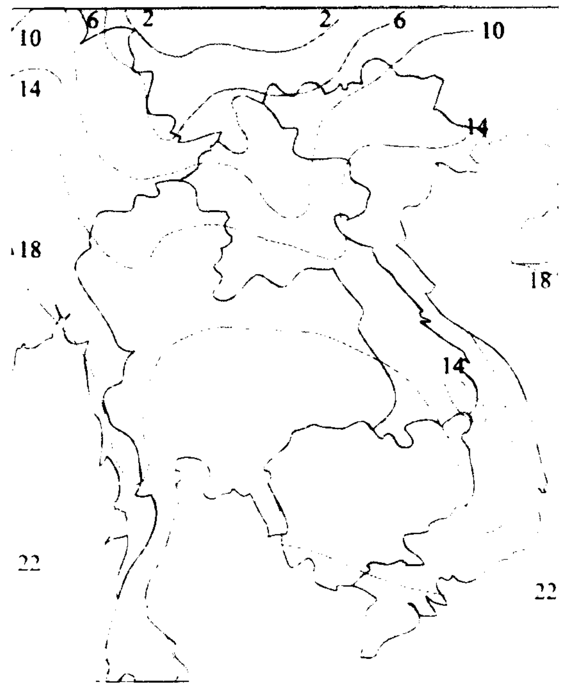


Figure 6-15. January Mean Minimum Temperatures (°C). The isopleths represent the average of all low temperatures during the middle stages of the northeast monsoon.

Hazards. Typhoons, although less frequent during the northeast monsoon, still occur. They bring in heavy rain, high winds, and wide-spread flooding. The most vulnerable locations are along the coast where high tides and storm surges can combine to raise sea heights well above normal. Thunderstorms are common even in this season. Turbulence, heavy rain, and strong downburst winds accompany even small thunderstorms. In the north, foehn winds occur with cold surges from the Himalayas. These hot, dry winds can raise temperatures. Vegetation dries very quickly, and fires become possible.

Trafficability. This area has predominantly mixed soil, a combination of coarse and fine grained soils. In portions of Thailand and along a northwest-southeast strip in central Cambodia, coarse-grained soils dominate. While the northeast monsoon is somewhat drier, most of this area remains moist. Trafficability over well-traveled (therefore relatively well-maintained) roads improves to fair, but most roads quickly become very poor when it rains. This is especially true in the south. Trafficability in the northern mountains remains poor year-round due to the rugged terrain.

General Weather. April marks the spring transition preceding the southwest monsoon; upper-level subsidence diminishes, and surface winds become light and variable. The Asiatic high collapses by the middle of March. It is replaced by the Asiatic low, which begins to develop by early April. The southwest monsoon is established by May and lasts through August; it is strongest in July and August, when the Asiatic low reaches its maximum strength. The southwest monsoonal flow is from mostly maritime air mass source regions. Thus, the air is moisture-laden and highly unstable. When the air hits land, orographic lifting begins to trigger convection. The flow is strongest from 900 to 1,500 meters but may be traced to 4,500 meters. This is the wet season for central southeast Asia, and the onset of the southwest monsoon brings heavy precipitation, gusty winds, and rainshowers. As the season continues, rain and rainshowers occur over a large area, and occasional thunderstorms develop. Precipitation typically begins at 0400L, with rain and rainshowers predominating until 1100L. Periodic breaks occur from 1100 to 1500L, and thunderstorms occasionally develop due to the increased surface heating. Finally, rain and rainshowers return until midnight. This is also the season most vulnerable to typhoon activity. The official season begins in June and goes through November, but tropical cyclones spin up earlier and later in this area. The greatest chance for a typhoon occurs when the NETWC migrates through this area.

Sky Cover. Skies are least cloudy during the April transition into the southwest monsoon, but cloudiness steadily increases as the season becomes firmly established in May and June. Beginning in June, partly cloudy days become more infrequent, and after mid- to late June, most locations report only 1-2 clear days a month. During the height of the southwest monsoon, cloudiness can persist throughout the day and night. Ceilings in valleys are generally higher than in the mountains, where clouds frequently obscure ridges. Low stratus ceilings predominate along the coast. Ceilings during the morning hours generally vary from scattered to broken stratocumulus/cumulus at 2,500-4,000 feet to broken to overcast stratus at 1,500-3,000 feet. Because of afternoon heating, orographic lifting, and the condensation of the low-level moisture, broken cumulus ceilings at 2,000-4,000 feet predominate by midday. When rain occurs during the evening, nocturnal cooling and evaporation of rain may cause stratus layers to lower below 1,500 feet. Predominant broken-to-overcast mid-level clouds are altostratus, altocumulus, and nimbostratus; cirrus clouds are also common this time of year. Figure 6-16 shows the percent frequency of ceilings below 3,000 feet. Broken-to-overcast layered clouds can be expected through 20,000 feet (see Figure 6-17). Typhoons, which are most likely to strike this area between June and November, pour moisture into the region. Mountains become cloaked with embedded thunderstorms. Ceilings below 1,000 feet are likely in higher terrain, but heavy storm clouds will drop bases below 500 feet anywhere.

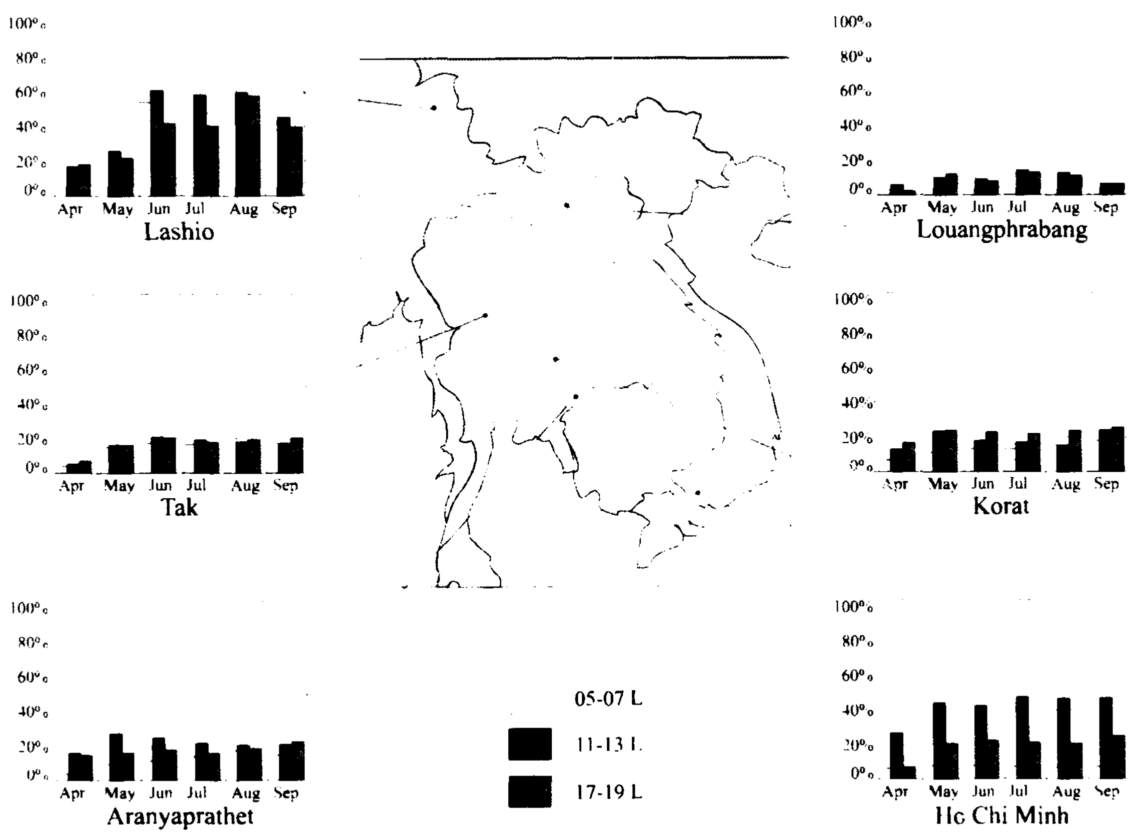


Figure 6-16. Southwest Monsoon Ceilings below 3,000 Feet. The graphs show a monthly breakdown of the percentage of ceilings below 3,000 feet based on location and diurnal influences.

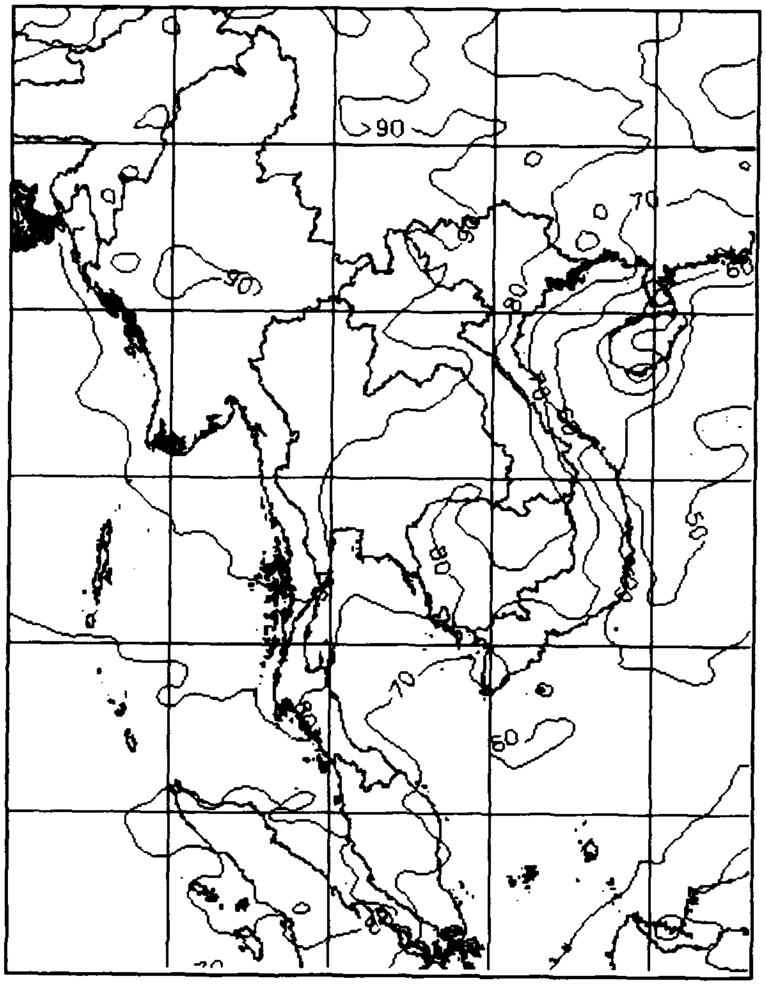


Figure 6-17. July 00Z Ceilings. These percentages represent the frequency of cloud ceilings at all altitudes.

Visibility. Overall visibility is somewhat better during the southwest monsoon than during the northwest monsoon because there are fewer smoke sources, and winds are generally stronger. Rain and morning fog are the primary restrictions to visibility during the southwest monsoon. Fog is common along the coasts and in the mountains, and morning visibility of less than 4,800 meters occurs frequently near river valleys. However, these foggy conditions rarely persist into the late morning. Generally, afternoon hours afford the best visibility over central southeast Asia. Afternoon haze reduces visibilities but rarely to below 8,000 meters. Visibility above 16 km is uncommon because of the high moisture content of the air. Rain and rainshowers frequently reduce visibility during early morning and late evening. Heavy rains or thunderstorms occasionally reduce visibility to less than 1,600 meters, but the prevailing visibility in rain is normally from 4,800 to 8,000 meters. Figure 6-18 shows the percent frequency of visibility less than 4,800 meters for selected sites. Typhoons moving through the area will drop very heavy rains, which will drop visibility for many hours. At the peak of the storm, visibility will become obscured by intense rain and drop below 1,600 meters.

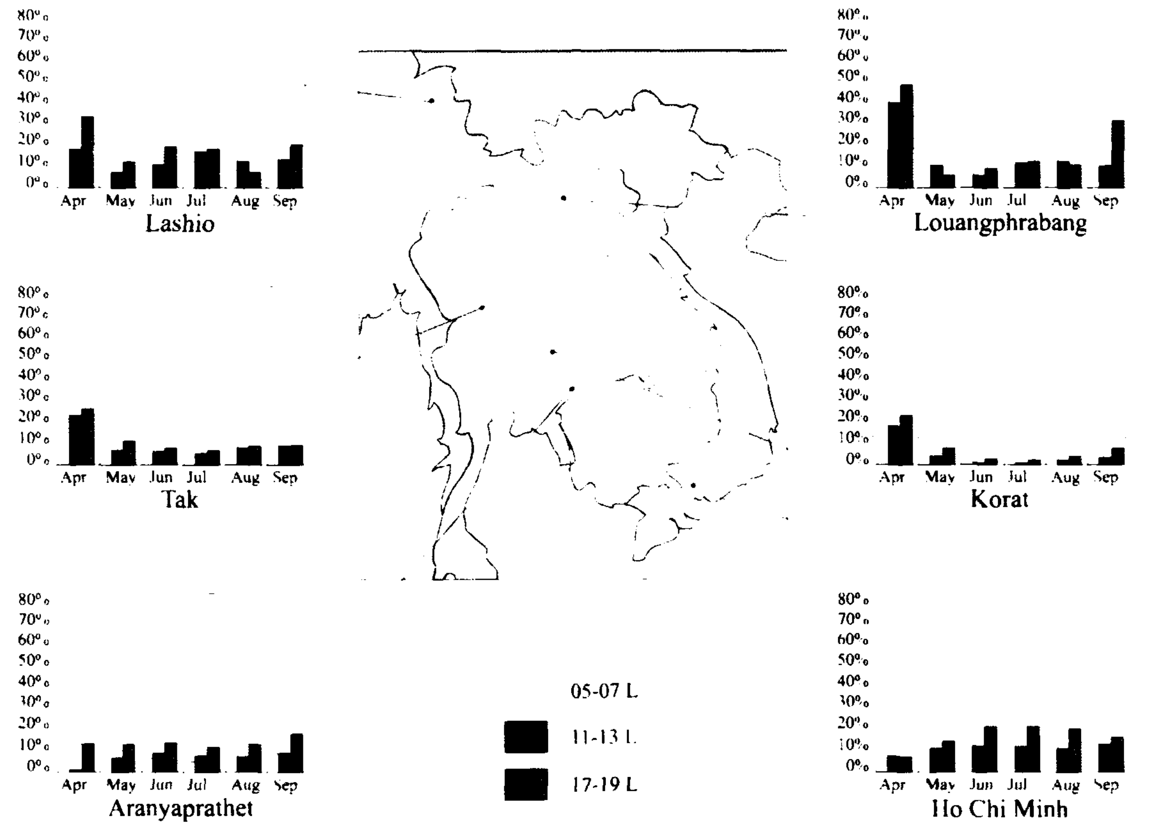


Figure 6-18. Southwest Monsoon Visibility below 3 miles (4,800 Meters). The graphs show a monthly breakdown of the percentage of visibility below 4,800 meters based on location and diurnal influences.

Surface Winds. Surface winds in central southeast Asia are influenced by a number of factors, but they are primarily controlled by the monsoonal flow. At the beginning of April, the northeast monsoon still influences surface winds, but by mid-May the winds transition to southwesterly. Southwesterly flow becomes firmly established in June and remains so until the end of August. During the height of the southwest monsoon, southwesterlies predominate to about 4,500 meters, but by late August or early September, they do not extend above 3,000 meters. Above 3,000 meters, winds become more westerly, and above 4,500 meters, they transition into the tropical easterlies. Terrain variations influence surface wind speed and direction, and channelling through mountain passes dramatically affects wind speeds. Mountain and valley winds and land/sea breezes also alter local winds. For more information on these effects see the *Diurnal Wind* section in Chapter 2. During the southwest monsoon, wind speeds over the area are slightly higher than during the northeast monsoon. Generally, surface winds are less than 15 knots, but speeds above 70 knots have occurred in association with intense convection. Ho Chi Minh City has recorded extreme speeds of 70 knots each month from June through September. Strong winds affect the coasts when these regions are most susceptible to subtropical cyclones (early in the season) and tropical storms and typhoons (especially during the middle to late southwest monsoon). While storm winds are blurted by terrain inland, coastal areas are battered by gale force and stronger winds. July 00Z and 12Z surface wind roses are shown in Figures 6-19 and 6-20, and July wind roses for all hours are shown in Figure 6-21. Calm winds are reported in the lowlands because inversions form at night. These inversions damp the effects of diurnal circulations.

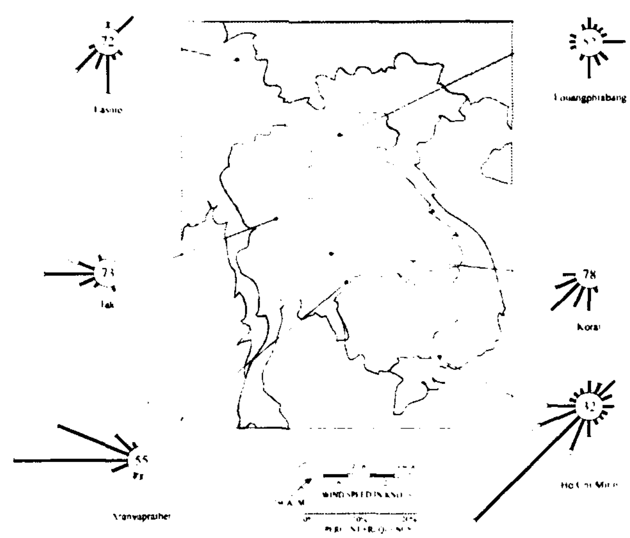


Figure 6-19. July 00Z (06L) Surface Wind Roses. The wind roses depict prevailing wind direction and range of speed for 00Z based on percent of frequency and location.

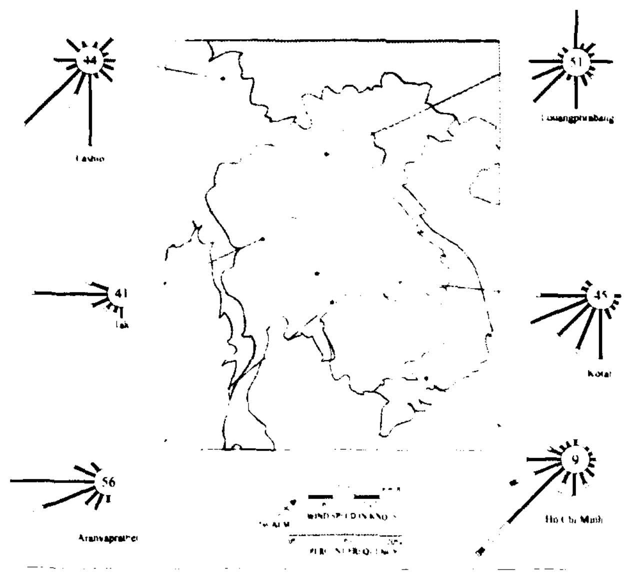


Figure 6-20. July 12Z (18L) Surface Wind Roses. The wind roses depict prevailing wind direction and range of speed for 12Z based on percent of frequency and location.

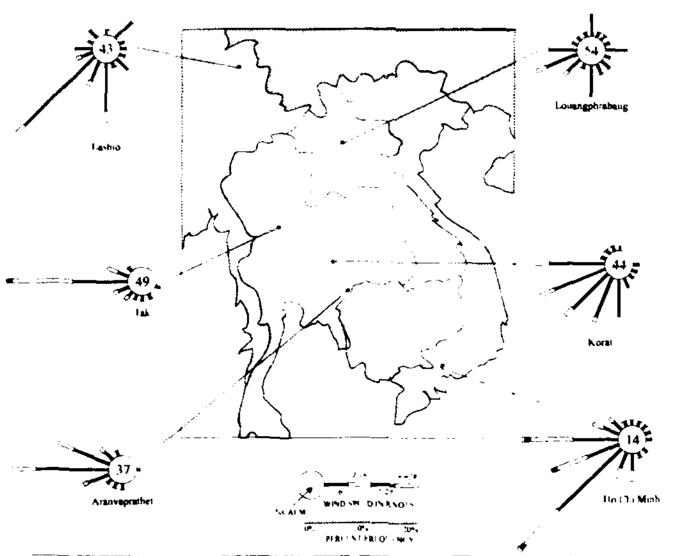


Figure 6-21. July Surface Wind Roses, all Hours. The wind roses depict mean prevailing wind direction and range of speed for all hours based on percent of frequency and location.

Upper-Level Winds. Upper-level winds blow steadily from the southwest at 10-15 knots up to the 20,000-foot level. Above that, easterly winds begin. By 25,000 feet, east winds at 15-20 knots prevail. This holds true to 50,000 feet where speeds may exceed 50 knots. The core of the easterly jet is south of this area.

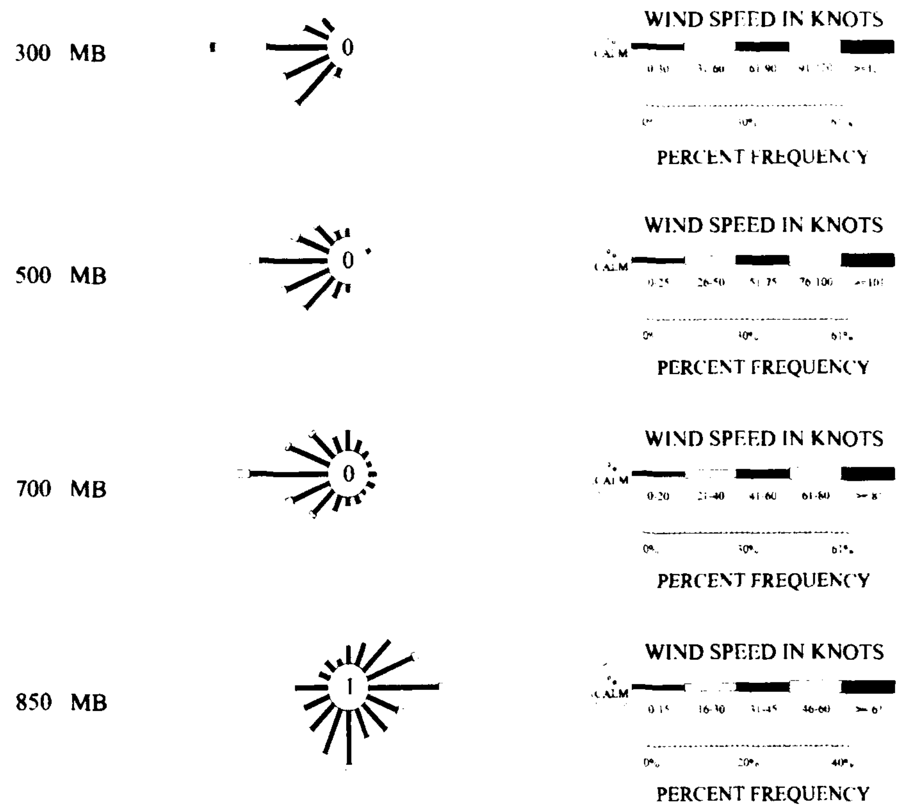


Figure 6-22. July Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 and 300 mb at Udonthani, Thailand. Note: Each wind rose has a tailored legend.

Precipitation. The southwest monsoon is central southeast Asia's wet season, and the amount of precipitation can be devastating. In 1966, much of the Mekong River valley from northern Laos to central Cambodia was flooded, causing considerable loss of life and property. Precipitation is heaviest on the windward side, or just beyond the crest, of mountain chains perpendicular to the southwesterly flow. Precipitation amounts in many locations can vary greatly year to year; however, very dry months have occurred when the monsoon was interrupted for long periods. Maximum precipitation amounts generally occur in August throughout most of central southeast Asia. Absolute maximums can exceed 800 mm a month, while minimums can drop to 0 mm a month. Tropical depressions and typhoons enhance rainfall amounts near the coasts, but they can also affect inland areas. In August 1966, Typhoon Betty dropped 310 mm of rain on Louangphrabang, Laos. Mountainous areas in the north generally receive the fewest rain and thunderstorm days, but the rainshowers there can produce precipitation amounts that rival totals in the south. Figure 6-23 shows April average precipitation. Figure 6-24 shows July average precipitation.

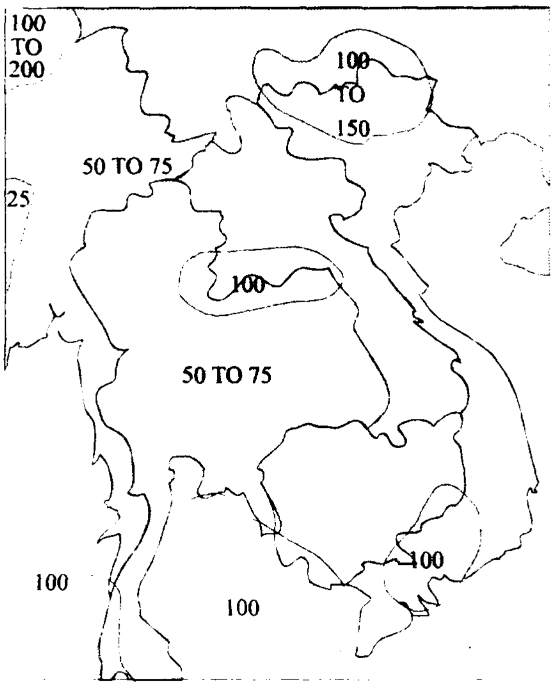


Figure 6-23. April Mean Precipitation (mm). The isopleths depict the average amount of precipitation received at the beginning of the southwest monsoon season.

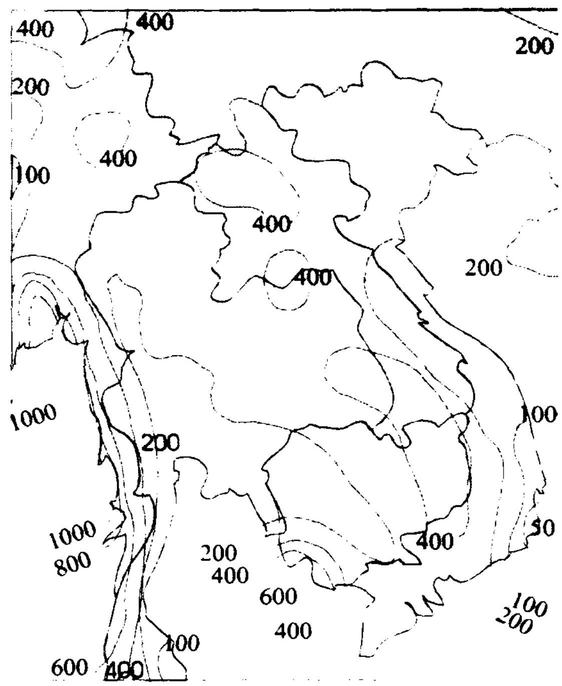


Figure 6-24. July Mean Precipitation (mm). The isopleths depict the average amount of precipitation received in the middle of the southwest monsoon season.

Thunderstorms. Thunderstorms generally occur during late afternoon, but orographic thunderstorms can occur anytime. Some locations experience almost daily orographic thunderstorms, but others may have only one or two a month. The Mekong Delta has abundant thunderstorm activity; thunderstorms occur almost every other day. The Korat Plateau experiences thunderstorms 15 days a month or more, with many storms persisting through the evening. Figure 6-25 shows monthly precipitation and thunderstorm days. The average thunderstorm is not violent, but when it is associated with a large-scale feature, such as a typhoon or tropical cyclone, it can become extremely powerful. Cloud clusters, mesoscale convective complexes, tropical storms, typhoons, and tropical waves generate significant thunderstorm activity during the southwest monsoon. Wind gusts from thunderstorms can exceed 70 knots, but these are most likely late in the season along the coast. Thunderstorm tops can reach 60,000 feet. Bases range from 1,500 to 4,000 feet, but thunderstorms embedded in stratiform precipitation may cause ceilings to fall to 500 feet or lower.

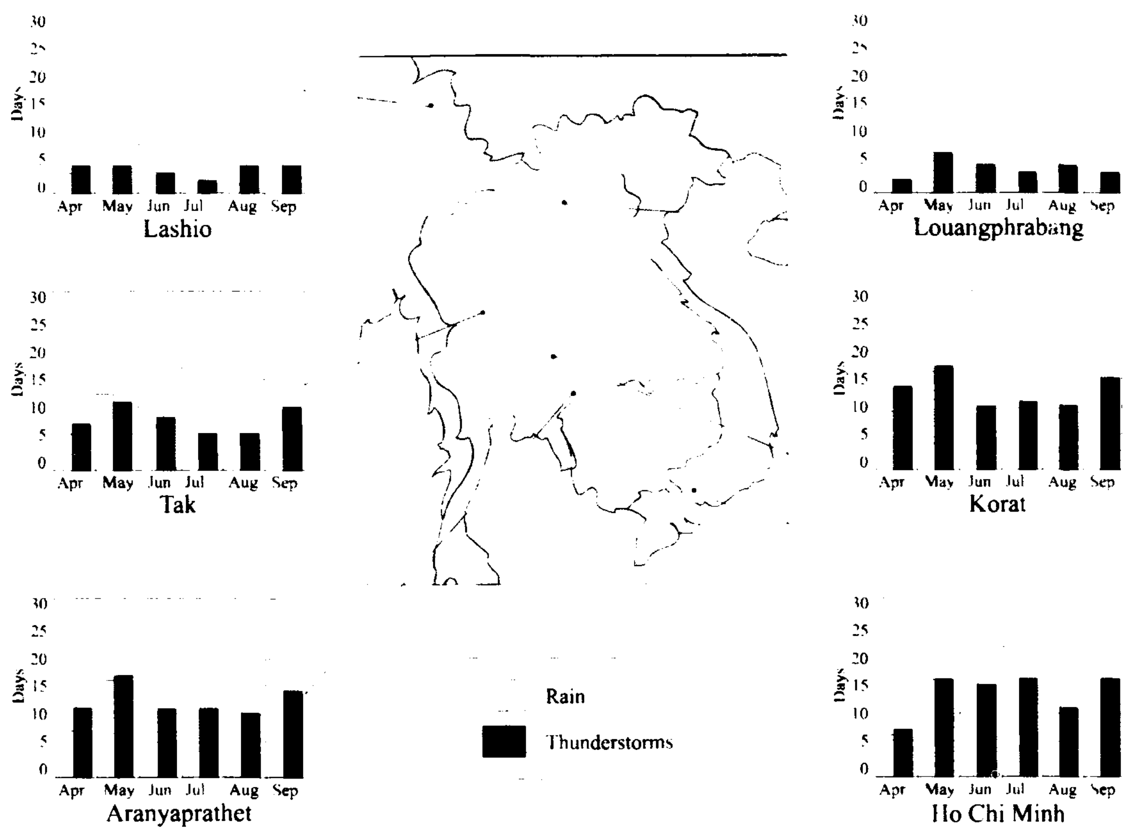


Figure 6-25. Southwest Monsoon Precipitation and Thunderstorm Days. The graphs show the average occurrence of rain and thunderstorm days for selected locations within central southeast Asia.

Temperatures. Generally, temperatures are high during the southwest monsoon, with little month-to-month variation. High temperatures and relative humidities of 70-95 percent can make conditions quite uncomfortable. Central southeast Asia's highest temperatures occur in April and May, when cloud cover is minimal and insolation provides maximum ground heating. As cloudiness increases during the season, average temperatures fall slightly from 34° to 32°C in Aranyaprathet and Tak, Thailand, and temperatures drop from 29° to 27°C in Lashio, Myanmar. Absolute maximum temperatures of 39°-42°C in May fall to 35°-38°C during the rainiest months of the season. Absolute minimums range from 13°C in the high elevations of Myanmar and Laos to the mid-20s over the Korat Plateau and along Vietnam's southeastern coast. Figures 6-26 through 6-29 show April and July maximum and minimum temperatures.

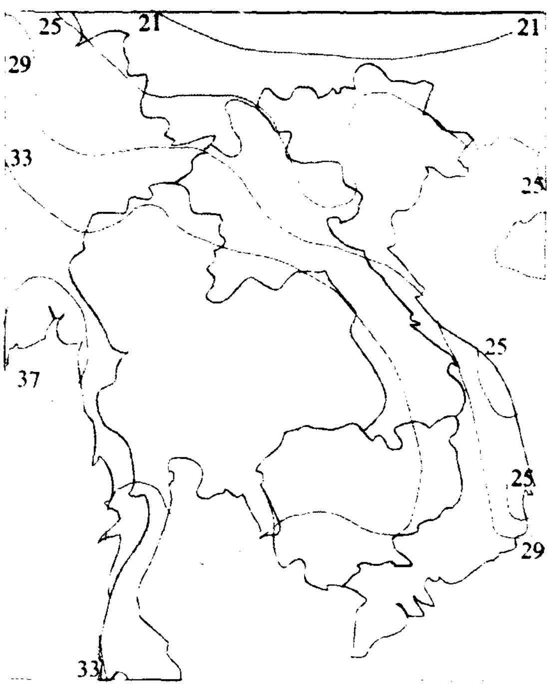


Figure 6-26. April Mean Maximum Temperatures (°C). The isopleths represent the average of all high temperatures during the early stages of the southwest monsoon.

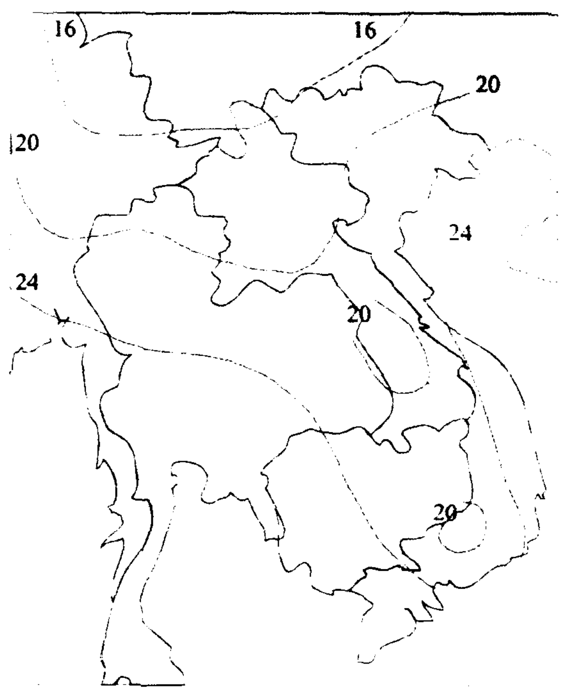


Figure 6-27. April Mean Minimum Temperatures (°C). The isopleths represent the average of all low temperatures during the early stages of the southwest monsoon.

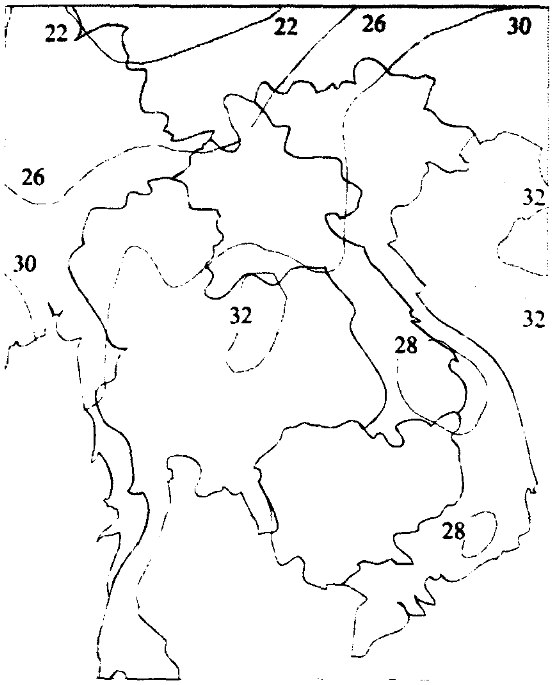


Figure 6-28. July Mean Maximum Temperatures (°C). The isopleths represent the average of all high temperatures during the middle stages of the southwest monsoon.

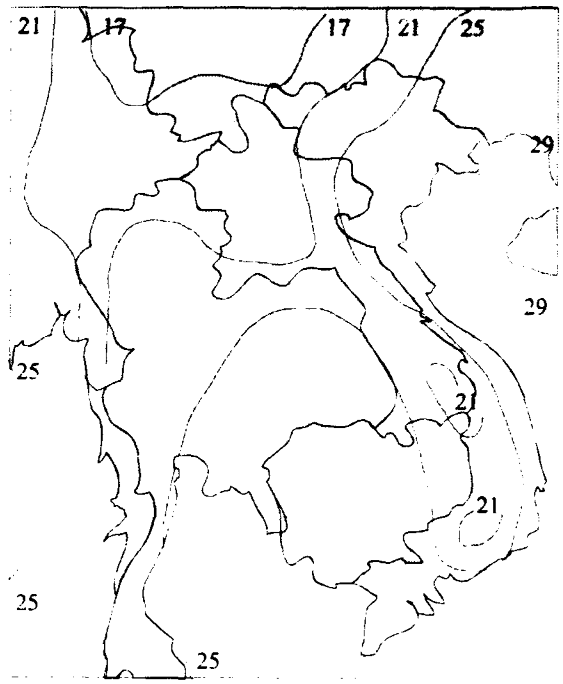


Figure 6-29. July Mean Minimum Temperatures (°C). The isopleths represent the average of all low temperatures during the middle stages of the southwest monsoon.

Additional Hazards. Tropical storms and typhoons occur mainly from the late southwest monsoon to the early northeast monsoon. These storms usually originate in the South China Sea but sometimes form in the Gulf of Thailand and the Gulf of Tonkin. During this period, tropical cyclones usually move westward from the South China Sea, bringing intense rain, flooding, and high winds. Tropical cyclones making landfall can cause rainfall of up to 400 mm a day and wind gusts of 70 knots in coastal regions. Flooding is fairly common near large rivers, especially during August. The most dangerous period for this region, in terms of likely typhoon strikes, is when the NETWC is transiting the area. Since the NETWC can waiver back and forth, the dangerous period extends beyond the usual June to November time frame. Typhoons can strike both very early and very late. The massive amount of rain associated with these storms cause both generalized flooding and flash flooding. Mountainous areas windward of the typhoon are most subject to flash floods. These occur with little or no warning and can cause life-threatening hazards in the blink of an eye.

Trafficability. Thailand, southern Laos, and part of Cambodia all have predominantly mixed fine- and course-grained soils. In portions of central Thailand and in a strip running northwest-southeast through central Cambodia, course-grained soils dominate. Heavy rainfall in areas of mixed soils results in poor to fair trafficability, while areas with course-grained soils experience fair to good trafficability. The rugged terrain of the mountains in the northern portion of the area degrades the trafficability to poor. The combination of heavy precipitation and fine-grained soils degrades Myanmar's trafficability to poor. The fine- and course-grained soils of Vietnam present good to fair trafficability, but with abundant rainfall, trafficability can be reduced to poor this time of year.

Chapter 7

CENTRAL VIETNAM

This chapter describes the geography, major climatic controls, special climatic features, and general weather (by season) for central Vietnam, as shown below.

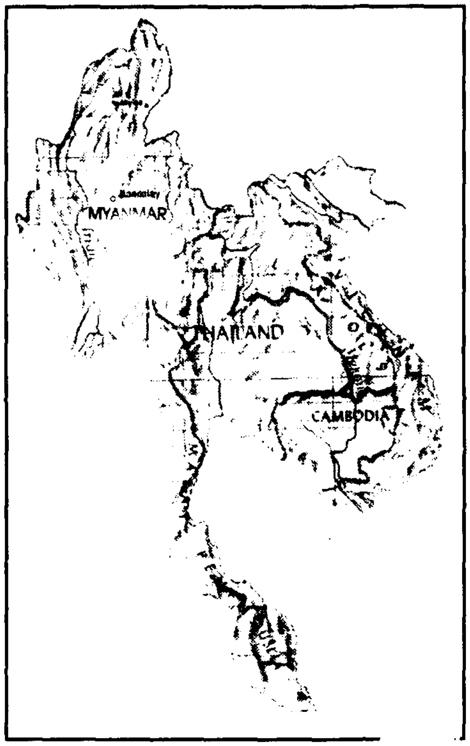


Figure 7-1. Topography. This r. major place names, rivers, and . in features.

Boundaries. The northern and southern boundaries of this zone are determined by the mean position of the 50-mm January precipitation line (precipitation exceeds 50 mm during January within central Vietnam). The Laotian border determines central Vietnam's western boundary, while the Gulf of Tonkin and the South China Sea constitute the zone's eastern boundaries.

Major Terrain Features. Except for a rather narrow coastal plain, central Vietnam is predominantly mountainous (see Figure 7-1). The Annam Mountains (also known as the Annamese Cordillera or *Truong-Son* in Vietnamese) are a series of eroded plateaus that extend north-south across the area and most of the rest of Vietnam. The mountains rise from near sea level to greater than 450 meters within [illegible] km of the coast in most areas. Further inland, the peaks range from 1,800 to more than 2,400 meters. The narrow coastal plain is composed of mud flats, sand dunes, and shallow lagoons that extend nearly 50 km inland in some areas. Elsewhere, the Annam Mountain range extends to the sea, breaking up the coastal strip. This series of eroded plateaus is oriented almost perpendicular to the two prevailing monsoonal airflows. During the southwest monsoon, the ridges shelter the narrow coastal plain. During the northeast monsoon, however, cloudiness and precipitation are enhanced over the eastern windward slopes, while relatively clear weather occurs over the rest of the country on the leeward side of the mountains.

Rivers and Drainage Systems. Rivers flowing from the Annam Mountains are generally shon, running through steep-sided valleys. Several rivers, including the Ngan Sau and Nguon Nay in the north and the Song Ba in the south, flow northwest-southeast through the terrain and drain into the Gulf of Tonkin and the South China Sea.

Central Vietnam contains no significant freshwater lakes, and the Gulf of Tonkin and the South China Sea are the only major bodies of water significantly influencing the area's climate.

Vegetation. The rugged highlands of the Annam Mountains are densely covered with tropical evergreens and subtropical deciduous forests. Bamboo is widespread in the undergrowth of the forests and along rivers. The coastal plain is composed of mud flats, sand dunes, shallow lagoons, and mangrove forests.

Monsoon Circulation and the Near Equatorial Tradewind Convergence (NETWC). The climate of central Vietnam is controlled by the monsoon circulation, which is in turn driven by the seasonal reversal of the pressure gradient over southeast Asia. The NETWC marks the dividing line between the northeast and southwest monsoons. From roughly October through March, the NETWC is south of the area, allowing the northerly flow from the Asiatic high to penetrate the area. During spring and summer, the NETWC moves north of the area, allowing the southerly flow of the southwest monsoon to predominate. Refer to Chapter 2 for a detailed description the monsoon circulation and the structure and movement of the NETWC.

Over central Vietnam, the southwest monsoon prevails from May to late September and is strongest in July and August when the Asiatic low predominates. The southwesterly flow is strongest at 1,500 meters MSL but can be found as high as 5,000 meters. The warm, moist air of the southwest monsoon brings rain to most of southeast Asia. The Annam Mountains shield central Vietnam from much of this moisture, however, and this zone receives most of its rainfall during the northeast monsoon.

October marks the transition into the northeast monsoon season over central Vietnam. By November, the northeast monsoon is well-established and continues to dominate through March. The northeast monsoonal flow largely originates as outflow from the cold Asiatic (Siberian) and North Pacific highs. Not only is the cold, dry air from the Asiatic high significantly modified during its extended flow over mainland China and the South China Sea. but the Himalayas prevent the coldest air from reaching central Vietnam. Unlike most of southeast Asia, central Vietnam receives abundant rainfall during the northeast monsoon. This is due to Vietnam's proximity to the South China Sea. In April, the northeast monsoon weakens as the transition to the southwest monsoon begins.

Tropical Cyclones. Tropical cyclones affect central Vietnam from June through December, with maximum cyclone frequency occurring from July to November. During May and June, tropical storms and typhoons usually cross the northern South China Sea and recurve into China. The cyclone tracks move south from July through November, and the storms strike the northern and central Vietnamese coast. Almost 40 percent of typhoons entering the South China Sea move inland over Vietnam. Typhoons bring torrential rains and damaging winds to the east coast and the eastern Annam Mountain range; the greatest destruction associated with tropical cyclones is caused by flooding from the heavy rain, abnormally high tides, and heavy seas. Widespread torrential rainfall floods river channels, lowlands, and delta regions and may wash out roads, communication lines, and airfields. Even in protected interior regions, the remnants of dissipating cyclones may cause widespread flooding.

Crachin. This is the local term for spells of extensive stratus, fog, and drizzle that occur along the northern and central Vietnamese coast. Crachin is occasionally observed as early as October, but it is far more common late in the northeast monsoon or during the transition into the southwest monsoon. Crachin produces thick stratus cloud decks, with bases frequently below 500 feet and thickness averaging 3,000-5,000 feet. Spells of crachin normally last 3 to 5 days, though it has persisted for more than 20 days in some cases.

General Weather. The transition into the northeast monsoon takes place in October, and the synoptic flow is weak until the northeast monsoon becomes well-established, normally in November. Low ceilings and decreased visibility are often reported during the northeast monsoon, especially on the eastern slopes of the Annam Mountains and along the coastal strip, where extensive precipitation falls. As air associated with the northeast monsoon moves across the relatively cool waters near the coast of central Vietnam, widespread stratus and drizzle develop. Farther inland, conditions are much improved, and stations on west-facing slopes report their lowest frequency of low clouds and their lightest precipitation of the year.

Variations in the Asiatic or North Pacific highs result in day-to-day changes in the strength and direction of the northeast monsoonal flow. The strongest northeasterly flow generally extends to about 1,500 meters. Therefore, unlike coastal areas, higher terrain experiences little cloudiness and rain; clear mornings with some valley fog and scattered-to-broken cumulus in the afternoon often prevail. Periodic breaks in the northeast monsoonal flow usually cause decreased cloudiness along the coast. Occasionally a surge of the northeast monsoon brings colder air to northern central Vietnam via a land route. By the time it reaches central Vietnam, this cold air mass has been modified extensively, though it is still rather cold by tropical standards; extreme lows may reach 0°C at high elevations.

Sky Cover. Cloudiness is at a maximum from the eastern side of the Annam Mountains to the coast (see Figure 7-2). Low ceilings are most common in the north. Along the coast, ceilings less than 1,000 feet occur 15 percent of the time in early morning, then they generally lift to 2,500 feet during afternoon. Farther inland, the moist flow dams up against the eastern slopes of the mountains, and ceilings can remain below 1,000 feet for extended periods. Crachin (described in Chapter 2) is responsible for the most prolonged cases of low ceilings. Crachin, which is brought on by long-term onshore flow, is occasionally observed as early as October; it is far more common later in the season, especially during the March and April transition. Crachin produces thick layers of stratus clouds, with bases frequently below 500 feet; cloud tops are normally near 3,500 to 5,500 feet.

Along the zone's western boundary, conditions are clearer since the layer of moist air associated with the northeast monsoon is usually too shallow to cross the mountains. Early morning stratus in steep-sided river valleys develops into ceilings less than 1,000 feet every 1 in 3 days; these ceilings dissipate by late morning. An occasional tropical wave, which may produce a middle cloud ceiling, occurs early in the season. Western locations have scattered afternoon cumulus clouds with bases between 1,500 and 3,000 feet; thin cirrus occurs above.

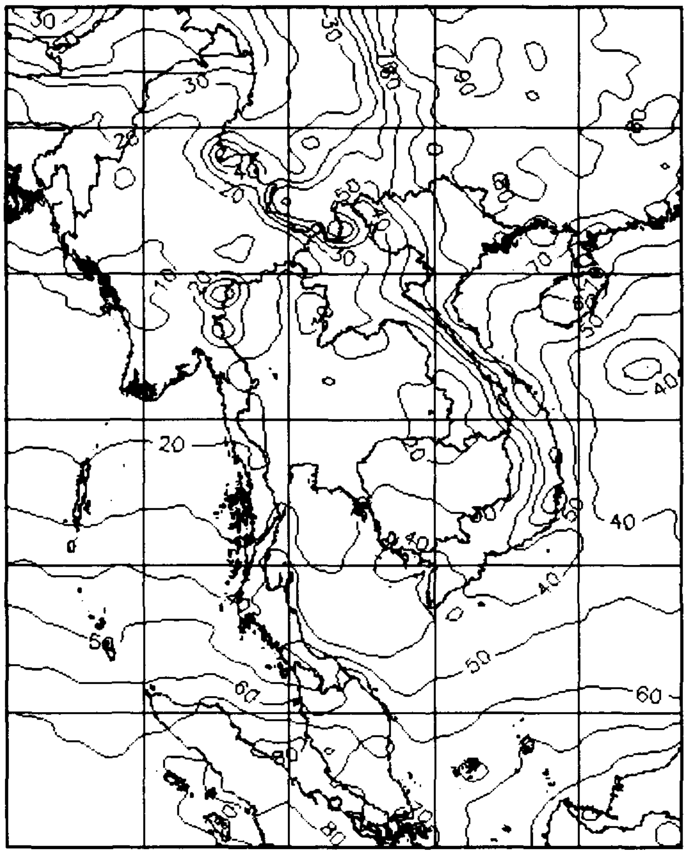


Figure 7-2. January 00Z Ceilings. The isopleths represent the frequency of cloud ceilings at any altitude during the middle of the northeast monsoon.

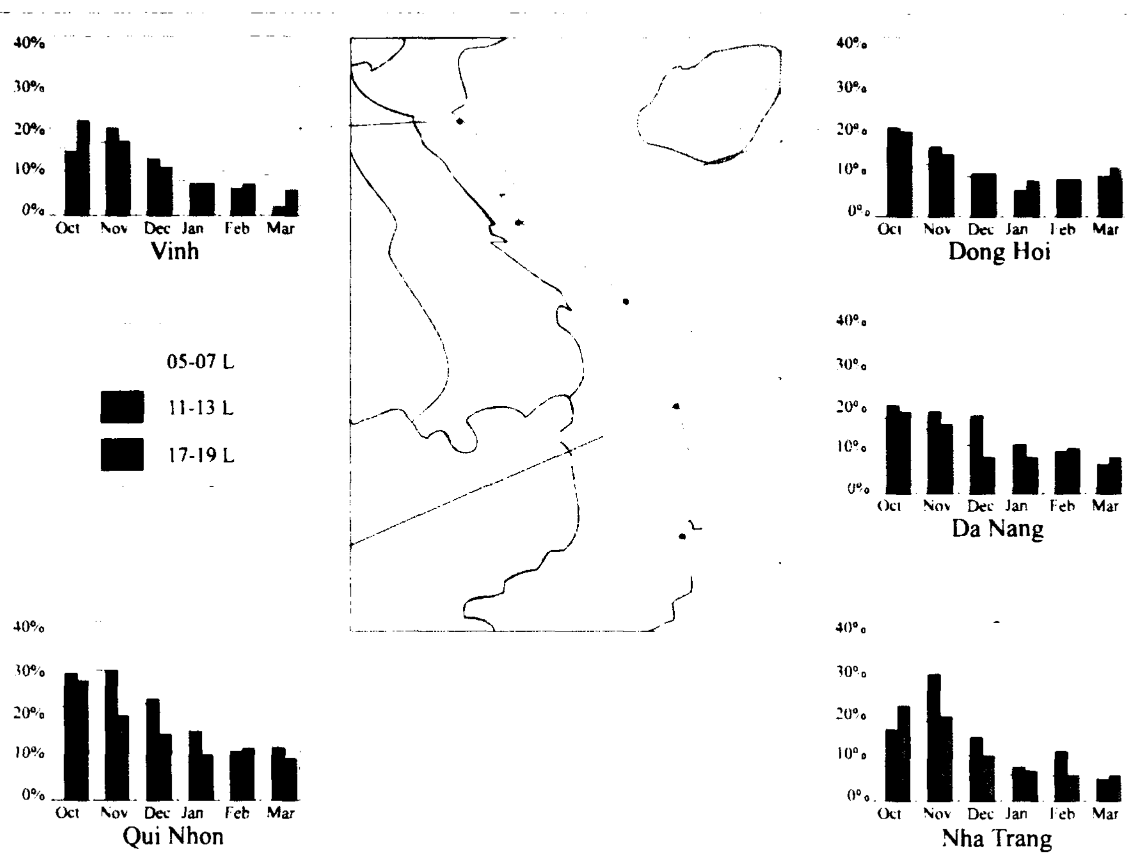


Figure 7-3. Northeast Monsoon Ceilings below 3,000 Feet. The graphs show a monthly breakdown of the percentage of cloud ceilings below 3,000 feet based on location and diurnal influences.

Visibility. Crachin causes prolonged episodes of low visibility along coastal areas, especially in the north (note the data for Vinh in Figure 7-4). Visibility is reduced below 3,200 meters for several days during spells of crachin, and it frequently falls below 800 meters.

The poorest visibility usually occurs in the early morning hours late in the season. Along the coast, visibility generally increases to 6,000 to 9,000 meters during the day. Farther inland along the east slopes of the mountains, however, visibility of only 800 to 3,200 meters can continue throughout the day.

Inland of the eastern Annam slopes, visibility rarely falls below 5 km. The exception occurs in narrow river valleys, where early morning fog occasionally reduces visibility for a few hours. After sunrise, visibility generally increases to 10 km or more. The highest mountain peaks occasionally have reduced visibility due to obscuration by clouds. Haze is prevalent during the northeast monsoon but seldom reduces visibility tc 'ess than 10 km.

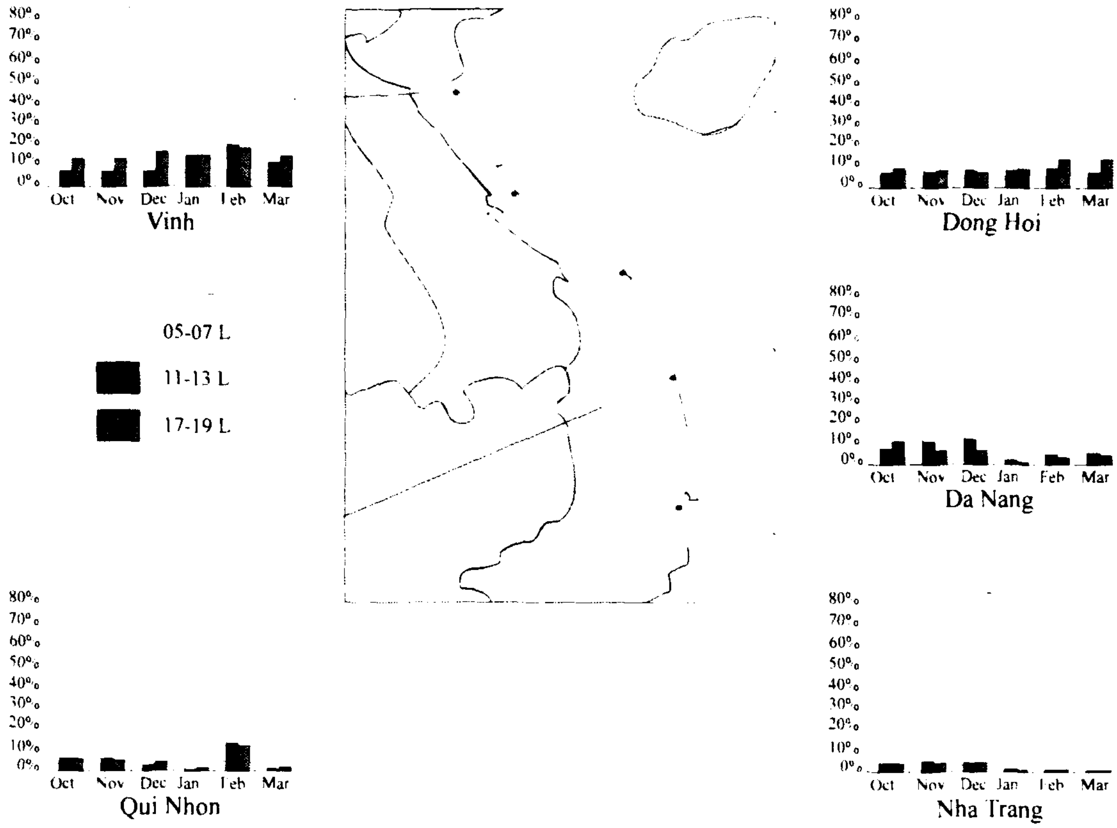


Figure 7-4. Northeast Monsoon Visibility below 3 Miles (4,800 Meters). The graphs show a monthly breakdown of the percentage of visibility below 4,800 meters based on location and diurnal influences.

Winds. Surface winds are generally light and variable during the October transition from the southwest to the northeast monsoon. By November, northeasterly flow is usually well-established; the winds become more easterly late in the season as the NETWC approaches the area. Land and sea breezes affect local surface winds along the coast; wind directions in the mountains depend on the terrain but are generally northerly. The strongest winds usually occur during the afternoon, with light drainage winds at night and during early morning. Drainage winds contribute to the northwesterly flow along the coast shown in the January 00Z wind roses (Figure 7-5). The strong, persistent northwesterly winds at Dong Hoi are due to channelling by local terrain.

Average surface wind speeds are less than 15 knots, with the highest speeds usually associated with northerlies. Speeds are light in the mountains unless winds are channelled through passes. Wind speeds can be higher along the coast as a result of the sea breeze associated with the cold Kuroshio Counter Current (see Chapter 2). Gusts above 20 knots are not uncommon during the afternoon. The sea breeze tends to give winds along the coast a more easterly direction. Figure 7-6 shows January 12Z winds.

Tropical disturbances can occur early in the northeast monsoon, and winds associated with a typhoon passing along the coast can exceed 100 knots. Due to the mountain barrier, however, extreme gusts associated with tropical disturbances do not penetrate inland.

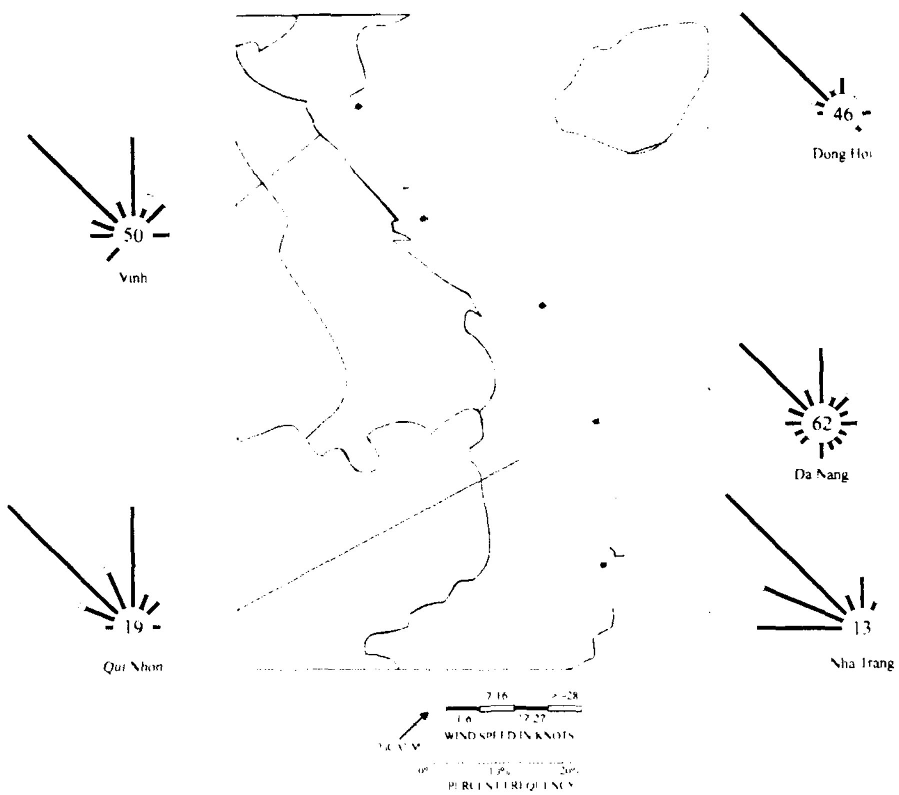
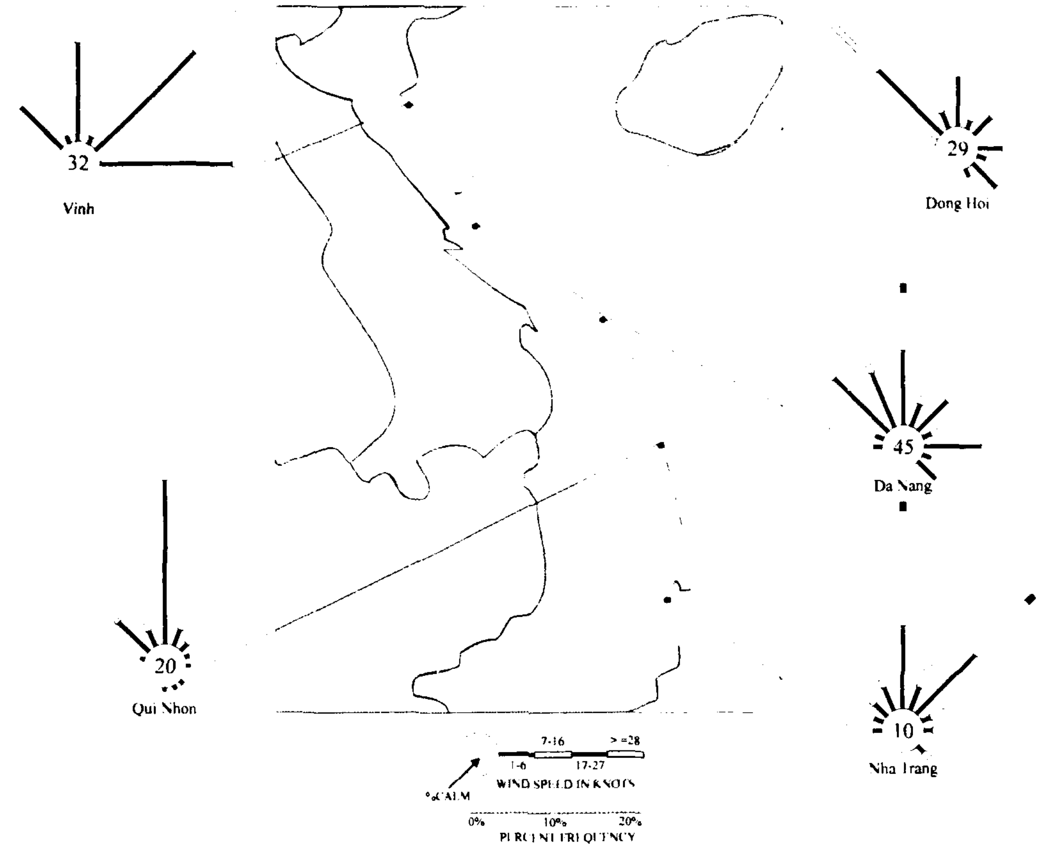


Figure 7-5. January 00Z Surface Wind Roses. The figure shows the prevailing wind direction and range of speeds based on frequency and location during the middle of the northeast monsoon.



Figures 7-6. January 12Z Surface Wind Roses. The figure shows the prevailing wind direction and range of speeds based on frequency and location during the middle of the northeast monsoon.

Upper-Level Winds. Up to 5,000 feet, winds are generally light and variable (5-10 knots) with an overall south or easterly component. Above that, they quickly shift to come from the southwest. By 10,000 feet, they are steady from the southwest at 10-15 knots. The direction remains the same through 50,000 feet and the speeds remain well below 40 knots. The jet stream is north of the area and does not usually have a direct effect. Indirectly, it carries low-pressure systems into the area from the west.

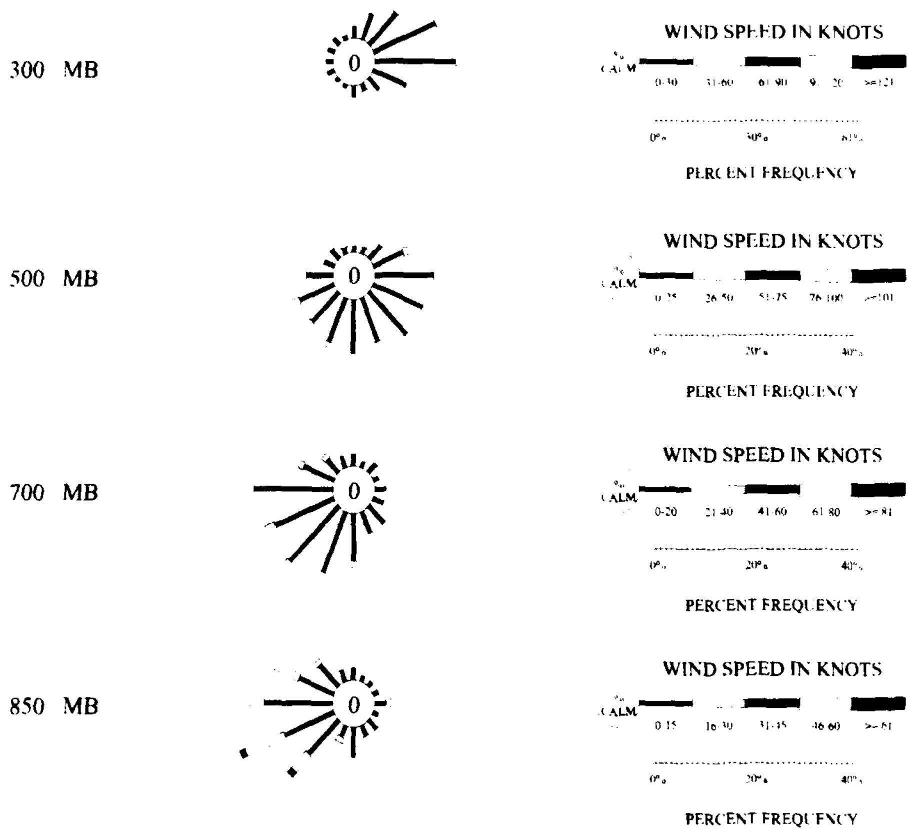


Figure 7-7. January Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 and 300 mb at Da Nang, Vietnam. Note: Each wind rose has a tailored legend.

Precipitation. Rainfall amounts are at a minimum in the higher terrain, but rainfall totals along the coast can be nearly as high as during the southwest monsoon (see Figure 7-8).

The eastern slopes of the coastal mountains and the coast itself experiences their highest number of rain days a month during the northeast monsoon. Rain falls mostly from stratiform clouds, and heavy precipitation is unusual (days with more than 13 mm of rain in 24 hours are rare).

Along the northern coast and over windward slopes exposed to the northeast monsoonal flow, average monthly rainfall amounts range from 500-700 mm a month in October and November to 100-200 mm a month the rest of the season. Tropical cyclones can bring up to 400 mm of rain in a day, and some coastal locations have reported up to 1,370 mm in one month.

Locations sheltered from the northeasterly flow receive much less rainfall than exposed slopes and coastal areas. Rainfall maximums range from 50 to 130 mm during the northeast monsoon. Most sheltered stations report only 1 to 2 days of rain a month during the height of the monsoon (December through February). Convective activity increases during the transition before the southwest monsoon season.

Light snow occurs on very rare occasions from November to February in the highest terrain. Snow generally falls late at night when surface temperatures reach their minimum; accumulation has never exceeded 1.2 cm. Snow has not occurred south of 15° N.

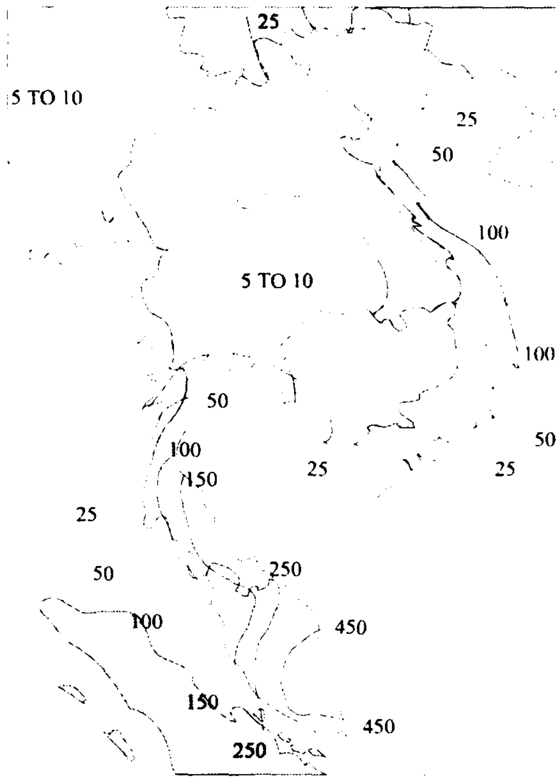


Figure 7-8. January Mean Precipitation (mm). The isopleths show the average January precipitation amounts for central Vietnam decreases significantly in areas sheltered from the northeasterly flow.

Thunderstorms. Thunderstorm activity is at a minimum during the northeast monsoon. Thunderstorms occur on 5-7 days during October, then they become very rare the rest of the season (see Figure 7-9). When they do occur, thunderstorm tops can reach 60,000 feet. Thunderstorm bases are highly variable; bases have been reported at less than 500 feet while embedded in stratus; however, outside of stratus, bases are generally between 1,500 and 3,000 feet.

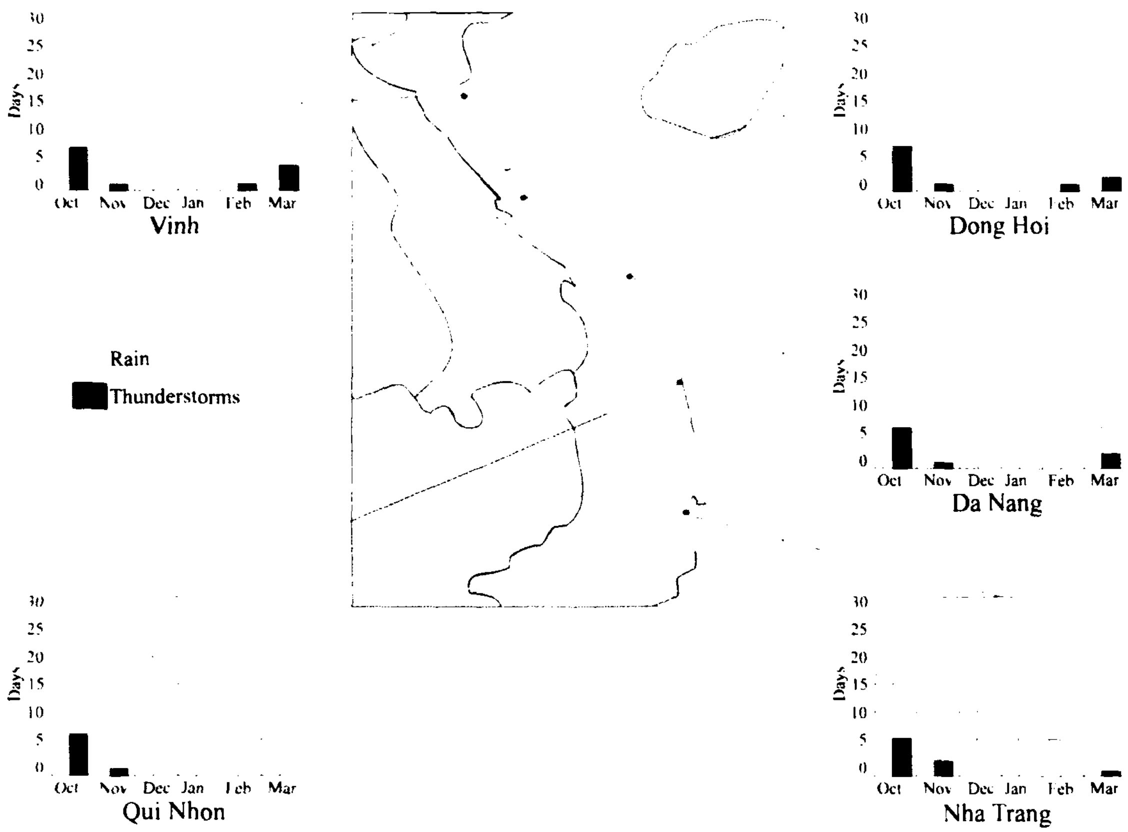


Figure 7-9. Northeast Monsoon Precipitation and Thunderstorm Days. The graphs show the occurrence of precipitation and thunderstorms days for selected cities within central Vietnam.

Temperatures. December through February are usually the coolest months of the year. The lowest temperatures occur in the mountains, where lows often fall to 5°-10°C. Extreme minimums have reached 0°C west of Nha Trang. Minimum temperatures occur when low-pressure centers develop on the lee side of the Annam Mountains, pulling colder air into central Vietnam. Minimums along the coast are somewhat higher due to moderating effects of the ocean; low temperatures here range from 15° to 21°C. Average high temperatures are near 20°C in the mountains and to 25°C or more near the coast. Southern central Vietnam has the highest mean temperatures during this season, averaging 27°C from Qui Nhon. Extreme maximum temperatures at Nha Trang range from 35°C in October to 36°C in March.

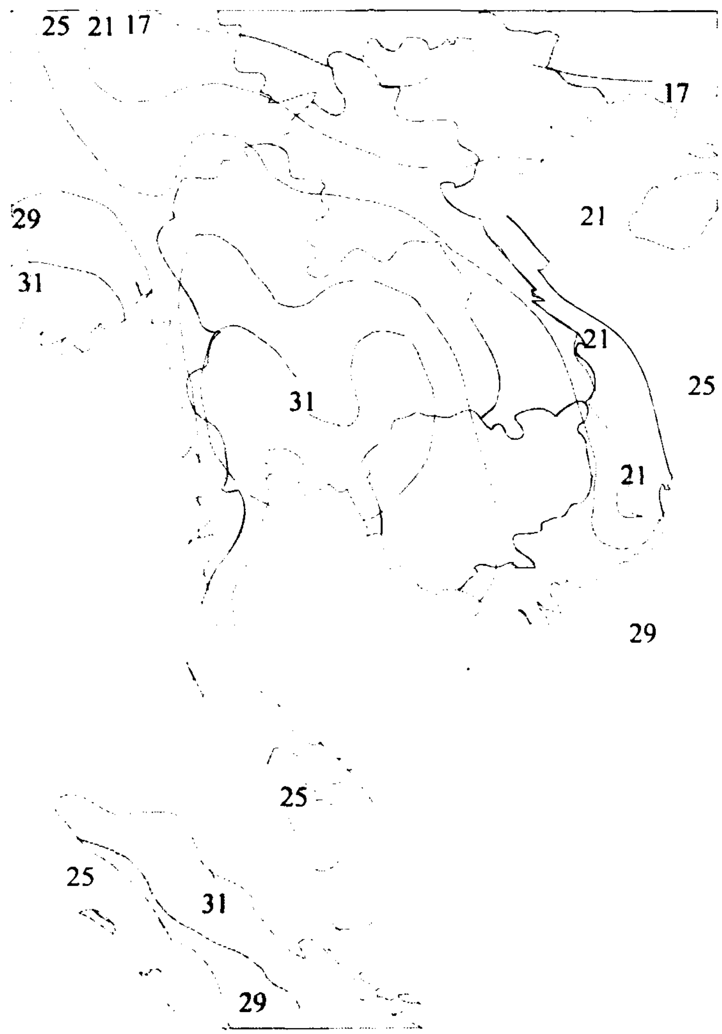


Figure 7-10. January Mean Maximum Temperatures (°C). The isopleths show the average of all high temperatures during the middle of the northeast monsoon.

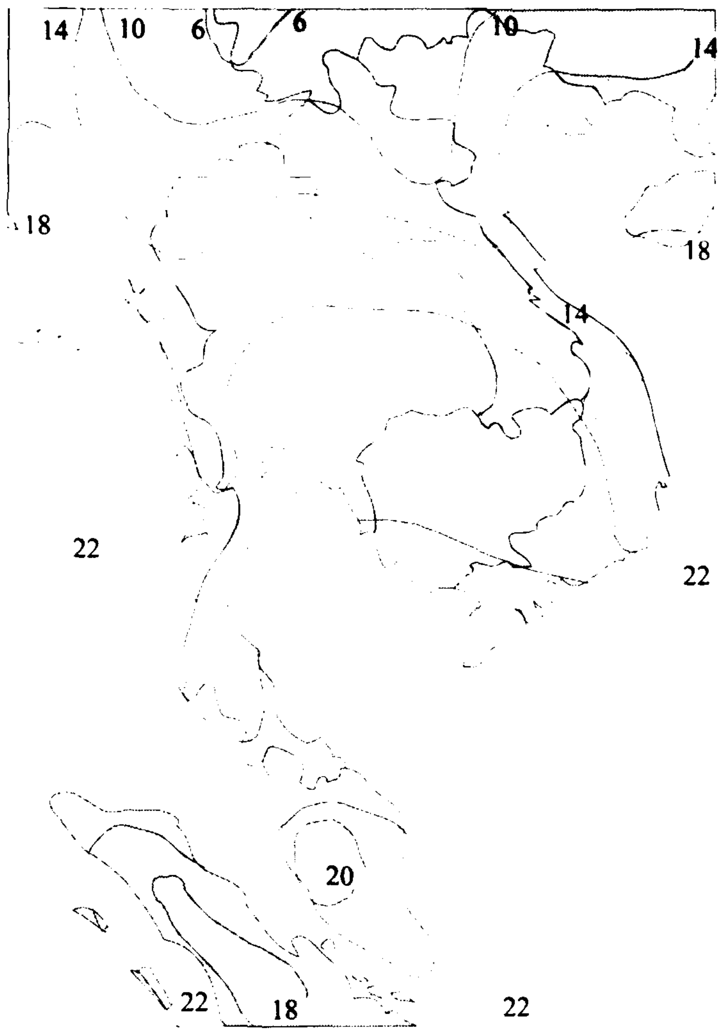


Figure 7-11. January Mean Minimum Temperatures (°C). The isopleths show the average of all low temperatures during the middle of the northeast monsoon.

Other Hazards. Tropical cyclones are most active during August and September, but they may occur any time from June through December. Tropical cyclones move westward from the South China Sea; prior to their landfall, the monsoonal flow is interrupted, causing clearing over the area. Heavy rainfall, up to 400 mm a day, and wind gusts of 70 knots or more can occur when a tropical cyclone strikes land. Even when a tropical cyclone merely approaches central Vietnam without making landfall, heavy showers and thunderstorms often occur. Typhoons are most likely to strike near the end of the southwest monsoon, but they do occur during the short fall transition season and the first few months of the northeast monsoon.

Trafficability. Mixed fine- and course-grained soils create fair to poor trafficability. This type of soil, the rugged topography, and a narrow coastal plain can greatly restrict mobility.

General Weather. The transition to the southwest monsoon begins in April, when the weakening Siberian high causes the northeast monsoon to retreat. April can be extremely hot, due to the lack of cloud cover and the weak flow pattern. The NETWC moves northward into or near central Vietnam in late April or early May, ushering in the southwest monsoon. During the height of the southwest monsoon, the NETWC is far to the north over China and difficult to find, but tropical disturbances moving along this low-pressure trough occasionally affect central Vietnam. Originating in Australia, the southwest monsoon starts as a warm and very dry air mass. As its passes over the warm equatorial waters, however, it is highly modified and becomes very moist and unstable in the lower layers. Upon reaching Vietnam, the air mass is distinctly maritime tropical.

Once the southwest monsoon becomes established, southwesterly flow brings in warm, moist, unstable tropical air with frequent showery precipitation and intermittently poor visibility and low ceilings. The southwest monsoon is generally considered the rainy season for much of central Vietnam, although the coast is considerably cloudier during the northeast monsoon. Unlike the stratiform rainfall pattern of the northeast monsoon, the convective precipitation of the southwest monsoon brings substantial amounts of rainfall over short time periods.

Sky Cover. The mountainous terrain produces large variations in cloudiness and ceiling heights. Clouds form more readily over the western slopes than over the eastern slopes or coastal regions. Within the mountains, there are many valleys sheltered from the moist southwesterly winds. As a result, these valleys have much less cloudiness than more exposed areas (see Figure 7-11). Stratus clouds are common in steep river valleys, though ceilings in the valleys are frequently higher than those over mountains, where clouds obscure the ridges at times.

Although the east coast experiences considerable cloudiness throughout the year, ceilings below 3,000 feet are infrequent during the southwest monsoon, due to the adiabatic drying of the air as it descends the Annam Mountains (see Figure 7-12).Cumulus clouds are the dominant cloud type during the southwest monsoon; tops frequently exceed 15,000 or 20,000 feet, and thunderstorm tops can extend to 60,000 feet. Skies are generally scattered to broken over the lowlands and broken to overcast over the mountains, where bases are often less than 3,000 feet. During heavy rainshowers, ceilings fall and obscure mountain tops. Completely clear skies are seldom reported in the mountains.

During the early morning, broken to overcast stratus ceilings frequently form below 1,000 feet in the mountains; these ceilings slowly lift during the late morning. By afternoon, scattered to broken cumulus clouds between 1,000 and 3,000 feet can be expected throughout much of central Vietnam. During the night, cloudiness tends to decrease.

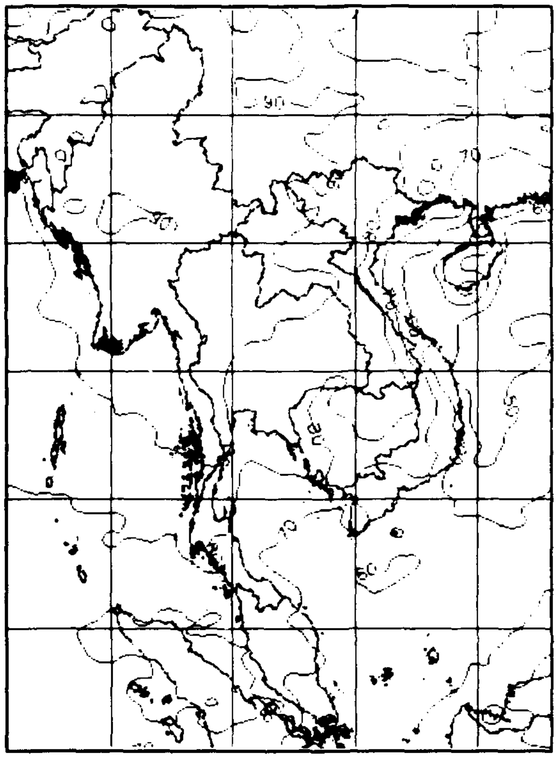


Figure 7-12. July 00Z Ceilings. The isopleths represent the frequency of cloud ceilings at any altitude during the middle of the southwest monsoon.

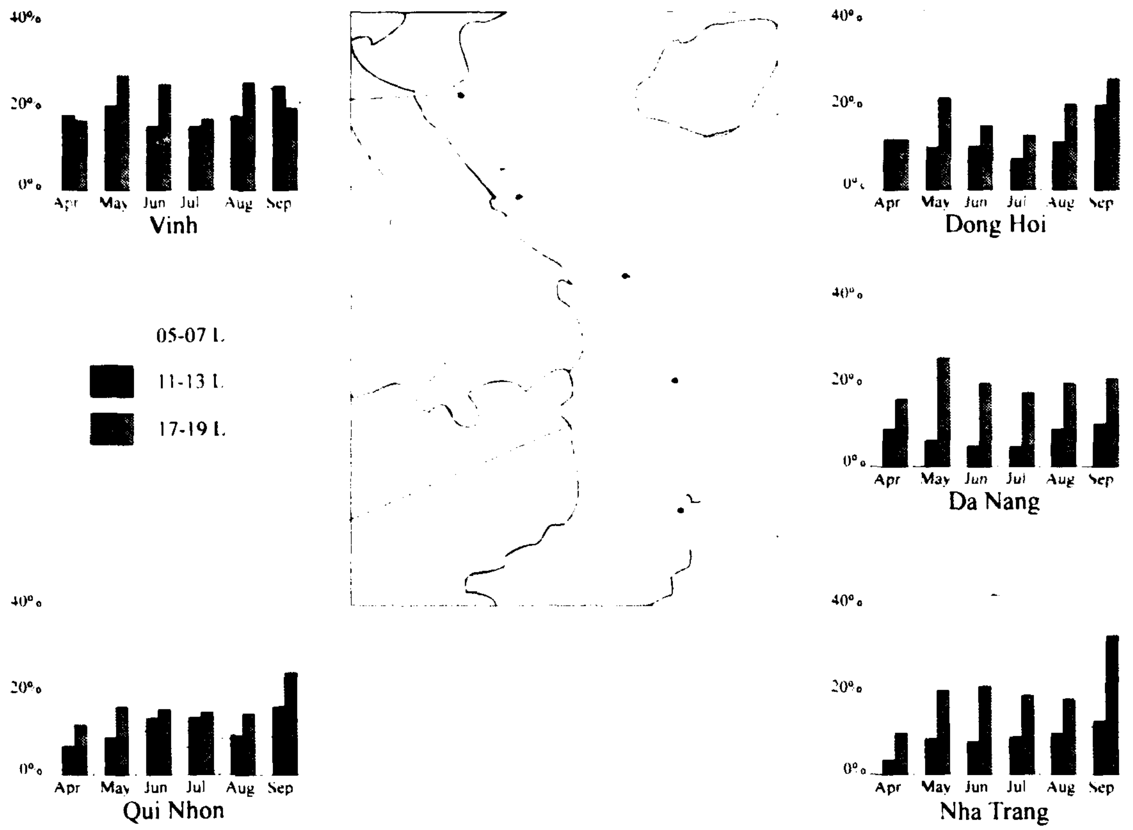


Figure 7-13. Southwest Monsoon Ceilings below 3,000 Feet. The graphs show a monthly breakdown of the percentage of cloud ceilings below 3,000 feet based on location and diurnal influences.

Visibility. Smoke, haze, fog, and rain are the chief causes of reduced visibility. Topography partially determines the distribution and duration of visibility restrictions. For example, sheltered locations in the highlands may report fog for 20 days, while a nearby station situated on a ridge and exposed to stronger winds may report only 5 days of fog during the same period. Radiation fog is common in the mountains during the southwest monsoon, and morning visibility is typically reduced to below 4,800 meters. Fog usually begins to dissipate by 0800L except in the deeper valleys, where it may persist until noon. In general, surface visibility is best during the afternoon. Visibility along the coast is generally good, as shown in Figure 7-13, but showers and thunderstorms can reduce the visibility to less than 8,000 meters. During intense storms, visibility can briefly fall below 1,600 meters.

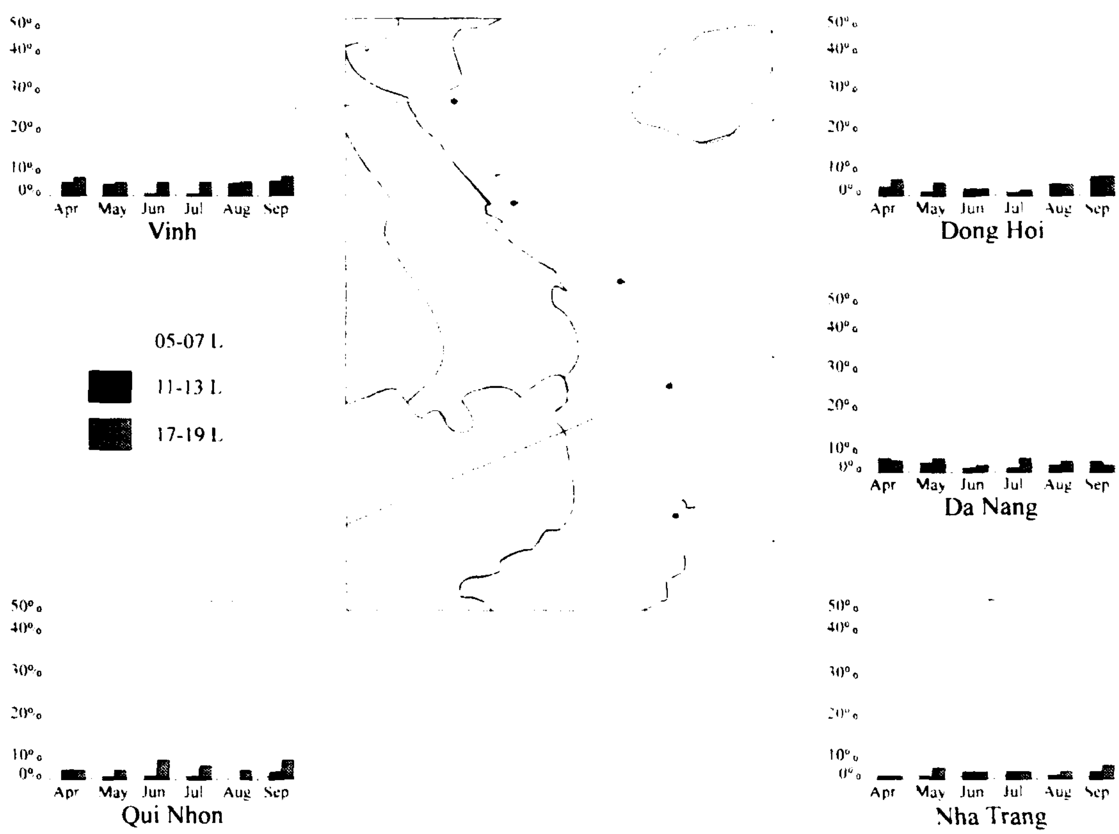


Figure 7-14. Southwest Monsoon Visibility below 3 Miles (4,800 Meters). The graphs show a monthly breakdown of the percentage of visibility below 4,800 meters based on location and diurnal influences.

Winds. Local diurnal effects strongly influence surface wind directions and speeds. During the day, valley winds flow upslope as the warm air rises from the valley floor. At night, mountain winds flow downslope when cool air sinks. Land and sea breezes are common along the coast, generally affecting an 18-km area on either side of the coastline. The effects of land and sea breezes are most pronounced where land configurations shelter the coast from the prevailing flow. In such places, the local wind may oppose the monsoonal flow at low levels. Land and sea breezes seldom extend higher than 900 meters. At higher levels, the monsoon winds are deflected by the Annam Mountains, but over the sea they are very constant. The mountains tend to channel the wind, with the flow generally paralleling the ridge line. Apart from these local variations, surface wind directions generally reflect the monsoonal flow. Figures 7-14 and 7-15 show surface wind roses for 00Z and 12Z.

Mean wind speeds are relatively low during the southwest monsoon. The strongest winds usually occur along or near the coast. There is a large diurnal variation in wind speed. Calm conditions are frequently observed during the night and early morning hours, and the highest wind speeds are observed in the afternoon. Terrain influences wind *speed* as much as wind *direction*. Speeds tend to be higher on windward mountain slopes, high plateaus, and areas where winds are channelled into narrow valleys. Speeds are considerably reduced in heavily forested areas where winds rarely exceed 5 knots. Winds may briefly exceed 50 knots during thunderstorms, and much higher speeds are associated with tropical cyclones.

Along the eastern coast, a phenomenon known as the "Winds of Laos" occurs during the southwest monsoon. These foehn (downslope) winds originate on the high plateaus of Laos and descend the eastern slopes of the Annam Mountains to the lowlands immediately adjacent to the water. The hot, dry "Winds of Laos" reach speeds of 25 to 30 knots and cause extreme evaporation and rapid temperature rises along their path.

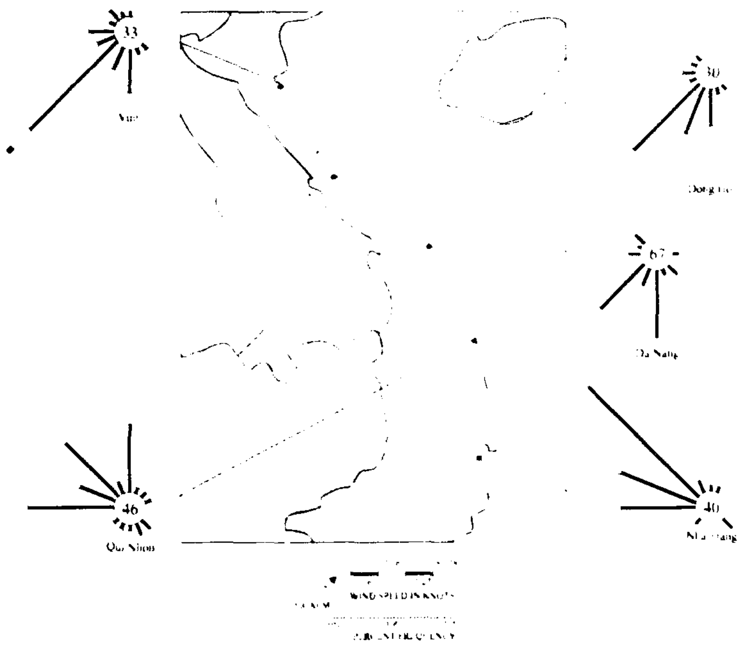


Figure 7-15. July 00Z Surface Wind Roses. The figure shows the prevailing wind direction and range of speeds based on frequency and location.

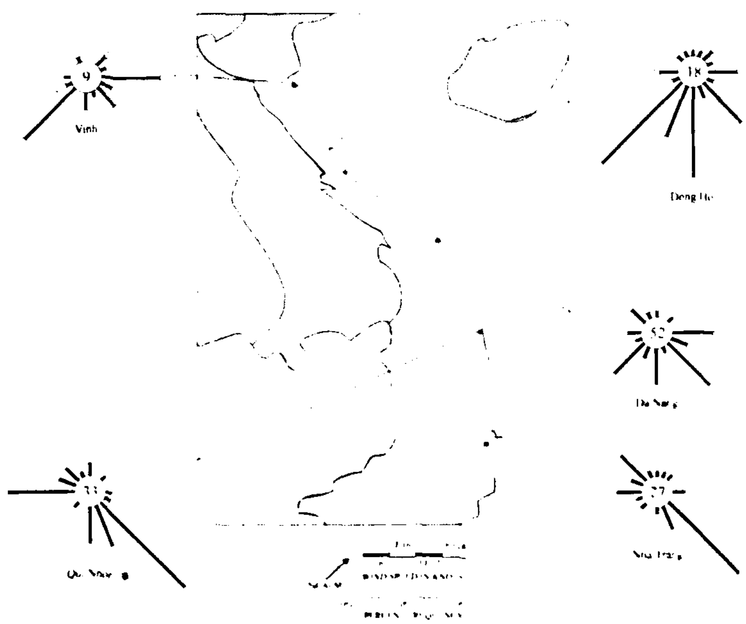


Figure 7-16. July 12Z Surface Wind Roses. The figure shows the prevailing wind direction and range of speeds based on frequency and location.

Upper-Level Winds. Winds blow steadily from the southwest at 10-15 knots up to the 20,000-foot level. Above that level, easterly winds take over. By 25,000 feet, east winds at 15-20 knots prevail. This holds true up to 50,000 feet. Above that level, wind speeds may exceed 50 knots. The core of the easterly jet is south of this area.

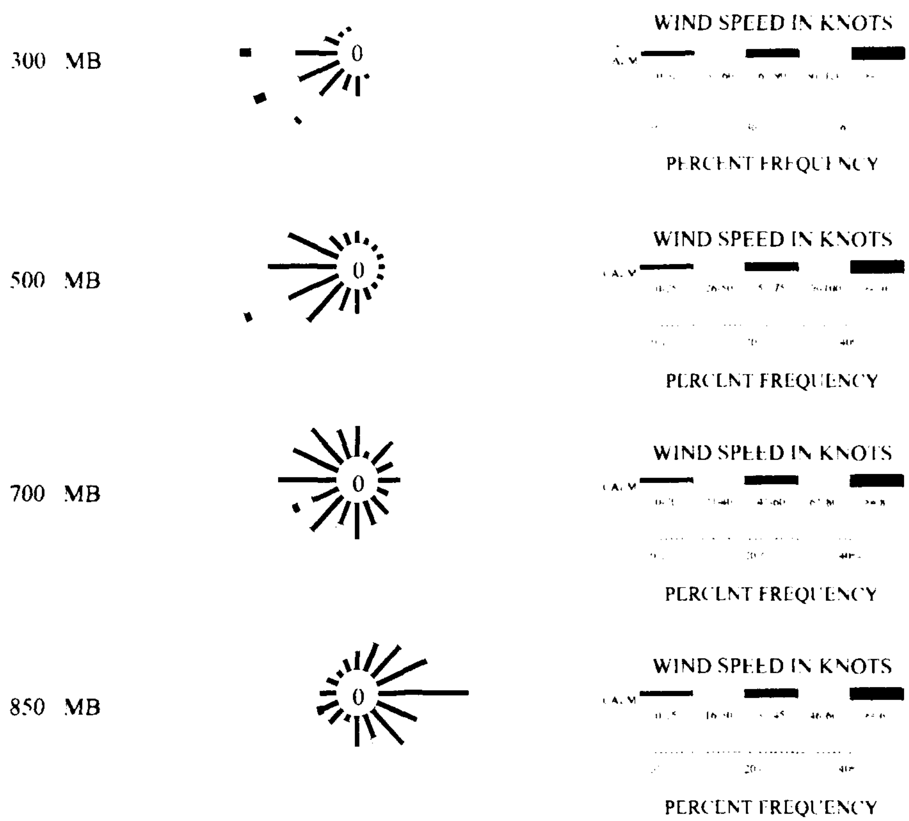


Figure 7-17. July Upper-Air Wind Roses. The wind roses depict wind speed and direction for standard pressure surfaces between 850 and 300 mb at Da Nang, Vietnam. Note: Each wind rose has a tailored legend.

Precipitation. Annual rainfall is substantial throughout central Vietnam, ranging from 900 mm in the south to 3,200 mm in the north. Monthly precipitation during the southwest monsoon generally varies from less than 20 mm at sheltered locations near the coast to more than 1,000 mm on exposed slopes; most places average between 50 and 250 mm a month (see Figure 7-16). Though much of central Vietnam has more rain days during the northeast monsoon, most locations receive more rainfall during the southwest monsoon. This is because precipitation during the northeast monsoon tends to be light rain from stratiform clouds, while precipitation during the southwest monsoon is more convective and intense. Although rainfall patterns vary throughout central Vietnam depending on exposure, most areas report their heaviest precipitation from May through September and occasionally into the October transition. The coast receives most of its rainfall from September through December. The Annam Mountains' shielding effects cause lighter precipitation along the coast than that received in neighboring countries, where flooding is common during the southwest monsoon.

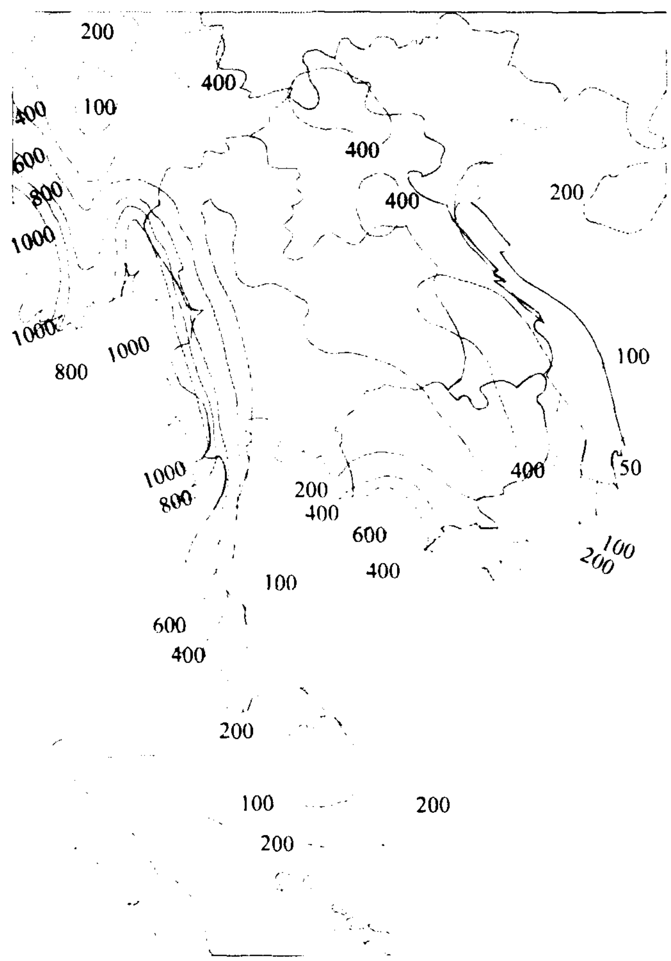


Figure 7-18. July Mean Precipitation (mm). The isopleths show average July precipitation amounts for central Vietnam decreases significantly in areas sheltered from the southwesterly flow.

Thunderstorms. Thunderstorms occur most frequently from April through October, with activity generally reaching a peak in late May. Thunderstorms are frequently accompanied by heavy rainfall, surface wind gusts exceeding 30 knots, severe turbulence, lightning, and hail. Data on hail is limited and tends to underestimate the frequency because it reflects only the hail that reaches the ground. Hail at flight levels often melts before reaching the ground. Thunderstorm tops reach 50,000 to 60,000 feet. Thunderstorms can occur at any hour, but they are most common during late afternoon and early evening. Thunderstorm activity usually reaches a peak between 1500 and 1700L; minimum activity is between 0700 and 1000L.

The most severe thunderstorms occur during the spring transition and early in the southwest monsoon. Extremely unstable conditions develop this time of year, often causing violent thunderstorms in the afternoon and evening; wind gusts of 50-80 knots, tornadoes and funnel clouds, hailstones 5 cm in diameter, and torrential rainshowers have been reported. During May, thunderstorms occur quite frequently in the mountains, due to the combination of moist, equatorial air and orographic lifting. Some mountain locations report up to 23 days with thunderstorms during May. The least activity occurs along the east coast from Da Nang to Nha Trang, where thunderstorms are reported on 2 to 5 days in April and 6 to 9 days in May (see Figure 7-17).

Thunderstorms occurring during the middle to late southwest monsoon are somewhat less violent than those earlier in the season, generally lasting only a few hours. Over most of the area, thunderstorm activity decreases in June and July, then increases again at the end of the season as the approaching NETWC enhances instability. From July to September, most places report from 6 to 11 days a month with thunderstorms, but along the coast, thunderstorms occur from 3 to 6 days a month. Over the mountains, especially the windward slopes, thunderstorms occur somewhat more frequently—about 10 to 15 days a month.

The widespread convective activity during the southwest monsoon season creates turbulence over central Vietnam. Severe turbulence should be expected within thunderstorms, and light to moderate clear-air turbulence frequently occurs nearby. The violent updrafts and downdrafts found in thunderstorms, especially those associated with the NETWC, occasionally produce large hailstones.

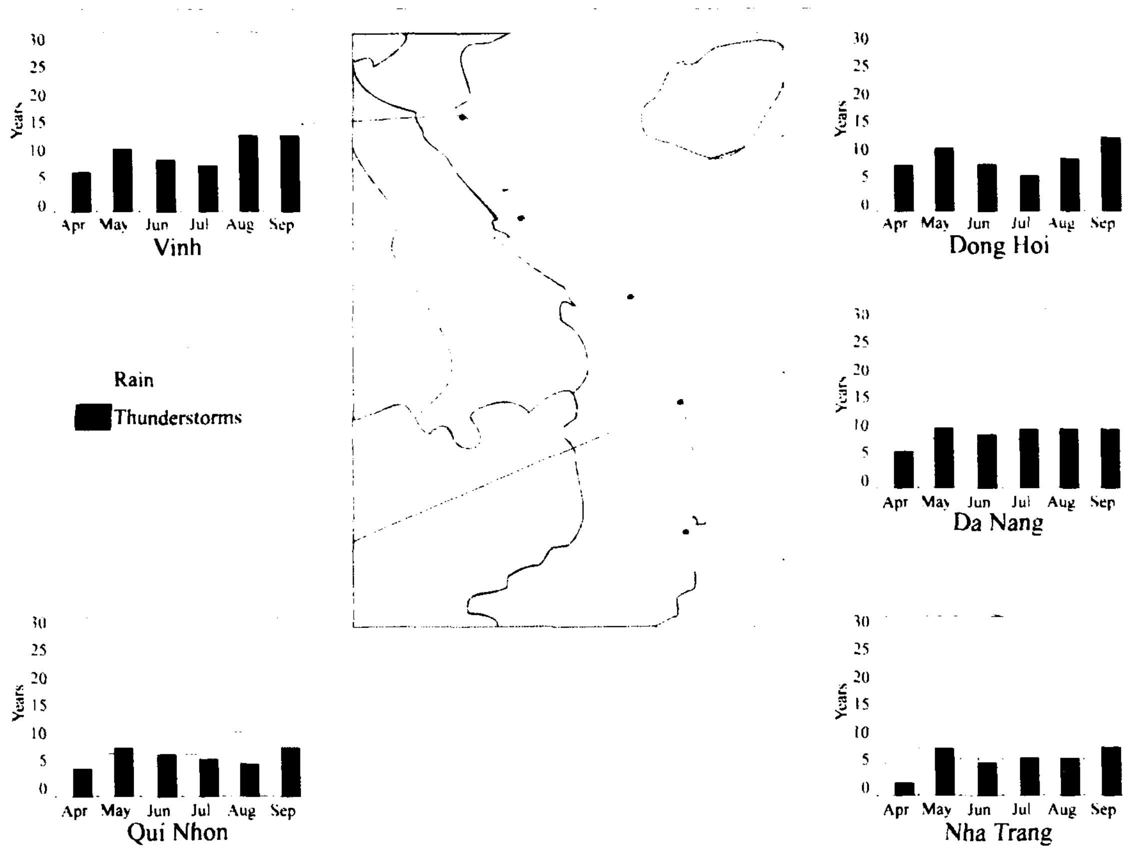


Figure 7-19. Southwest Monsoon Precipitation and Thunderstorm Days. The graphs show the occurrence of precipitation and thunderstorms days for selected cities within central Vietnam.

Temperatures. The hot and humid conditions associated with tropical weather prevail during the southwest monsoon (see Figures 7-18 and 7-19). In the highlands, the highest temperatures are recorded during the spring transition, whereas along the east coast June through August are the hottest months. The highest observed temperature during this season is 42°C at Qui Nhon, and the lowest observed temperature is -1°C at Dalat (high in the Annam Mountains). Mean temperatures in the mountains range from 18° to 27°C, while along the coast means are in the mid-20s to mid-30s from June through August. Daily maximums range from the low 30s along the coast to the mid-20s in the mountains. Average lows range from the low 20s in the mountains to the mid-20s along the coast. Cloudiness in the mountains decreases insolation (causing lower maximum temperatures) and slows outgoing nocturnal radiation (causing higher minimum temperatures).

Relative humidity is very high in the early morning, with averages of about 75 to 95 percent; it is somewhat lower in the afternoon, reaching about 40 to 85 percent. Along the east coast, the humidity is actually lower during the southwest monsoon than during the northeast monsoon, since the air dries at it descends the mountains. The rest of central Vietnam, however, experiences maximum humidities during the southwest monsoon. In forests, where wind speeds are restricted and temperature ranges are smaller than over open ground, high relative humidities are common. In this area of diverse topography and ground cover, large microclimatic variations in temperature exist and should be considered when planning operations.

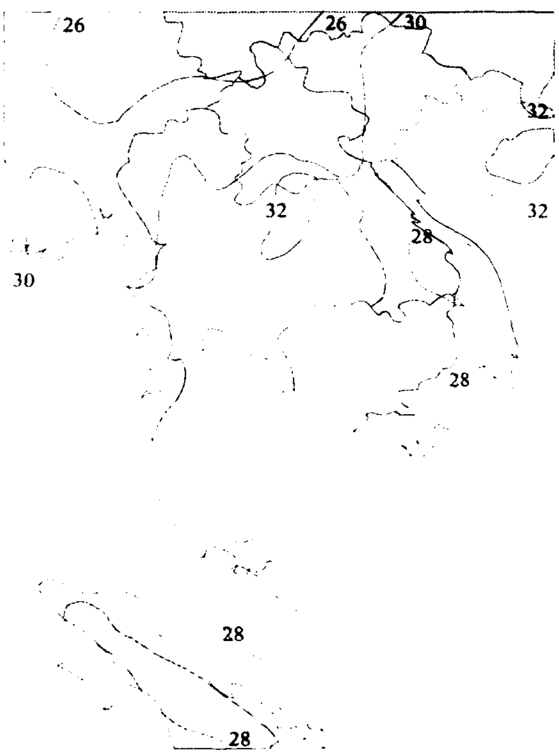


Figure 7-20. July Mean Maximum Temperatures (°C). The isopleths show the average of all high temperatures during the middle of the southwest monsoon.

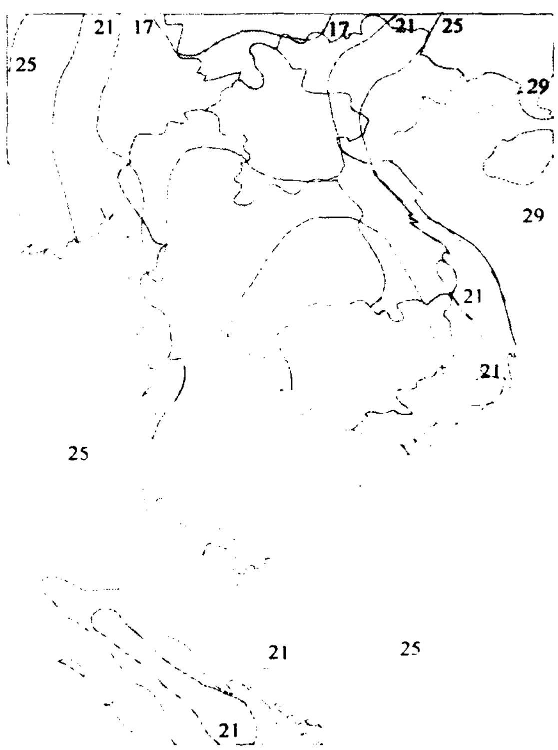


Figure 7-21. July Mean Minimum Temperatures (°C). The isopleths show the average of all low temperatures during the middle of the southwest monsoon.

Additional Hazards. Tropical cyclone activity usually begins in June and lasts through December, with maximum cyclone frequency occurring from July to November. During May and June, tropical storms and typhoons usually cross the northern South China Sea and recurve into China. From July through November, the cyclone tracks move south, and the storms strike the northern and central Vietnamese coast or pass close enough to adversely affect the area. Almost 40 percent of the typhoons that enter the South China Sea move inland over Vietnam; as many as 11 tropical storms have hit the Vietnamese coast in a single year. Some storms move all the way across the mountains into northern Laos before losing their strength.

The typhoons affecting Vietnam are similar to hurricanes that frequently strike the southeastern coast of the United States. Approximately 80 percent of the typhoons affecting Vietnam and the South China Sea originate in the Pacific Ocean east of the Philippines; the remainder originate over the South China Sea itself. Typhoons bring torrential rains to the east coast and the eastern Annam mountains. Wind speeds in tropical cyclones affecting central Vietnam are typically about 45 knots at 80 km from the center, though much higher speeds are possible with strong typhoons. The damaging effects of these winds are generally confined to coastal regions and the eastern Annam slopes. Flooding from heavy rain, abnormally high tides, and heavy seas causes the greatest destruction. Rough seas may severely damage coastal installations and even drive shipping aground. Widespread torrential rainfall floods river channels, lowlands, and delta regions and may wash out roads, communication lines, and airfields. Even in protected interior regions, the remnants of dissipating cyclones may cause widespread flooding.

Trafficability. Mixed fine- and course-grained soils create fair to poor trafficability. This type of soil, the rugged topography, and a narrow coastal plain can severely restrict mobility.

Chapter 8

The Malay Peninsula

This chapter describes the geography, major climatic controls, special climatic features, and general weather (by season) for the Malay Peninsula, as shown below.

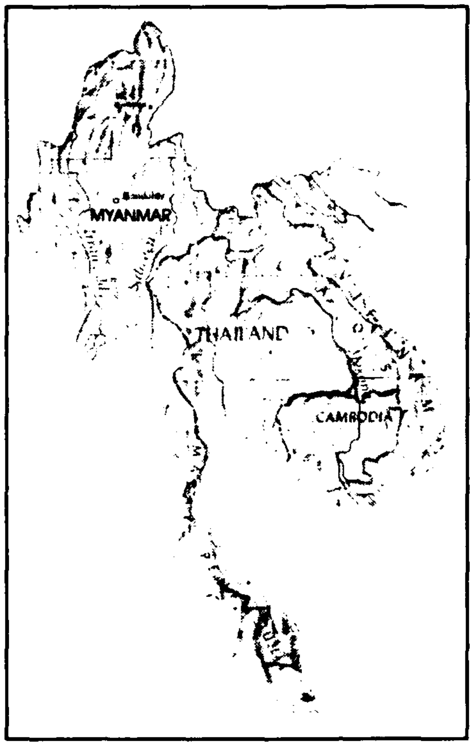


Figure 8-1. Topgraphy. This map shows major place names, rivers, and terrain features.

Boundaries. This chapter describes the climate of the Malay Peninsula, which includes the city-state of Singapore, most of eastern peninsular Thailand, and peninsular Malaysia. The country of Malaysia occupies portions of the Malay Peninsula and the South China Sea island of Borneo. The portion on the Malay Peninsula is known as Malaya. The Malay Peninsula has a truly equatorial climate; it is wet year-round, and its diurnal temperature variation exceeds its annual temperature variation. The northern boundary of this zone is the line north of which the mean January precipitation falls below 50 mm. This zone does not include the western coast of peninsular Thailand, which is discussed in Chapter 5.

Topography. This zone extends roughly 1,000 km from the border of Myanmar to the shallow Johor Strait and the island-state of Singapore (see Figure 8-1). The Strait of Malacca separates the Malay Peninsula from the Indonesian island of Sumatra. The width of the Malay Peninsula approaches 330 km at its broadest point, and many islands dot the waters off both the east and west coasts. A series of mountain ranges and associated highlands dominates the central core of the peninsula, and over half the land area is 150 meters or more above sea level. The main range runs down the spine of the peninsula. Composed primarily of granite, this range spans more than 480 km from the Thai border southward, with an average width of 48 to 64 km. The elevation for the entire length of the range rarely drops below 900 meters, and the highest peak in the main range is Korbu (2,183 meters). The highest peak on the entire peninsula is Tahan, which rises to 2,187 meters in northern Malaya. The rolling to mountainous terrain continues northward into Thailand where ridge elevations average 1,500 meters.

These mountain ranges divide the northern two-thirds of the peninsula into east and west coastal

regions. The coastal lowlands on either side of the mountainous interior are 15 to 80 km wide. Extensive plains allowing *padi* (irrigated rice) cultivation are found in northern Malaya but do not represent the typical landscape of most of the Malay Peninsula. Dotted with numerous small hills, the peninsula's southeastern territory is covered by the lowlands of Johor and is poorly drained despite the area's many small rivers. Mangrove swamps form the coastline of most of the west coast from Perlis to Johor, but the east coast typically has sandy beaches. The east coast is fully exposed to the South China Sea, while the landmass of Sumatra shelters the west coast from the Indian Ocean.

More than two-thirds of the island of Singapore lies less than 15 meters above sea level, and the highest point (Bukit Timah) stands at only 160 meters. Singapore's central hills, formed primarily from granite, give way to generally flat, alluvial soils in the east and northwest-southeast tending ridges in the west and southwest. Singapore's dense network of streams is insufficient to drain the island during the frequent torrential rainstorms, so local flash flooding is likely. In fact, flooding represents Singapore's greatest natural hazard.

Rivers and Drainage Systems. The Malay Peninsula is cut by numerous small rivers, generally flowing east and west from the interior to the sea. The longest is the Pahang River, which runs for 434 km; other important rivers are the Kelantan (which flows north) and the Perak. Because of the high year-round precipitation, these rivers never run dry and are nearly always navigable, although extensive silting in many rivers limits navigation to canoes and rafts. The abundant precipitation causes widespread annual flooding, especially during the transition to the northeast monsoon (October and November) as the Near Equatorial Tradewind Convergence (NETWC) crosses the region on its southward trek. A secondary flood period occurs in April as the NETWC advances across the region moving northward at the start of the southwest monsoon. When these spring floods and the spring tides coincide, the results can be especially destructive in coastal areas. Flash flooding associated with brief torrential rains is common throughout the year, though the high water subsides quickly.

Vegetation. Under the favorable influence of its hot, humid climate, the Malay Peninsula is a land of lush plant life. Woody varieties constitute most of the growth, but lianas, ferns, low shrubs, and flowering bushes abound everywhere. Cleared land exists only in major settlement areas along the coast or on river banks for varying distances inland. Much of the land that has been cleared has been replaced by palm and rubber tree plantations; if these regions are added to those naturally covered, the forest area constitutes about 90 percent of total land area.

All uncleared areas are commonly referred to as jungle, but this nomenclature is not entirely accurate. The mangrove and nipa palm areas near the western coasts are really swamp forests; they are treacherous underfoot and almost impenetrable. Most of the rain forest found at higher elevations contains towering, bare-trunked trees, mostly hardwoods. Most trees are about 30 meters high, but some rise as high as 60 meters. Trees are so close and the canopy is so dense that the forest floor is in perpetual shade, allowing only a thinly scattered undergrowth of flowers and low shrubs to exist. In other areas of the rain forest, where the soil was derived from underlying strata of limestone, the trees are not as tall and the canopy is more open, permitting undergrowth so luxuriant that a true jungle exists.

Monsoon Circulation and the NETWC. The northeast and southwest monsoons dominate the climate of the Malay Peninsula, with only brief transition periods (normally 4 to 6 weeks) between the monsoons. Air flowing southwestward from the high-pressure areas over Siberia and the North Pacific toward the equatorial low-pressure belt characterizes the northeast monsoon, which occurs from roughly November through mid-March. From mid-May to September, thermally driven low-pressure cells in Asia cause the airflow across Malaysia to reverse, bringing the southwest monsoon.

The NETWC migrates annually across Malaysia during the short transition seasons between monsoons. Winds are generally weak and variable during these periods, and widespread low-level convergence within the NETWC usually brings cloudiness, showers, and thunderstorms. Malaysia is part of the Northern Hemisphere winter's most convectively active region. With the strong vertical mass flux, moist tropical air, and high-surface heating, this region is particularly favorable for convection.

Oceanic Influences. In addition to the year-round strong solar heating resulting from the zone's proximity to the equator, the ocean waters surrounding the Malay Peninsula exert a profound influence on the climate. Sea-surface temperatures vary little during the year, remaining near 27°C. Therefore, the water exerts a moderating effect that helps maintain consistently high temperatures and humidities over most of the area throughout the year.

Topographic Influences. The rugged topography of the Malay Peninsula significantly influences the climate. Due to the air's marked convective instability, high moisture content, and high temperatures, very little lift is required to produce abundant cloudiness and rainfall. However, the terrain can also contribute to the occurrence of local agricultural droughts. During the northeast monsoon, the central mountain ranges cause a rain-shadow effect in regions to their west. During the southwest monsoon, the high mountain ranges of Sumatra cause a similar effect, and much of the area receives its minimum precipitation during June and July.

In many parts of the country, upslope and downslope flow strongly affect cloudiness and rainfall amounts at stations that may be only a short distance apart. While thick cloud banks appear on the windward slopes and often over the peaks of mountain ridges lying in the path of the monsoonal flow, downslope flow tends to clear the skies over leeward slopes. This clearing is especially evident during the northeast monsoon. Topography also influences local winds such as land and sea breezes and mountain and valley winds throughout the year. (See Chapter 2 for a discussion of these local wind phenomena).

Transitory Weather Features. The Malay Peninsula is too far south to be directly affected by extratropical cyclones and frontal systems, though the zone is affected indirectly by low-pressure systems crossing China. The leading edge of the cooler air associated with these systems occasionally sweeps south to the northern Malay Peninsula after the low passes, bringing extensive cloudiness and rain. This phenomenon is limited to the northeast monsoon season. Apart from these rare cold air outbreaks, three primary types of transitory phenomena affect the zone, as described below.

Tropical Storms. Most of the zone is too close to the equator to be affected by tropical cyclones and typhoons. However, tropical depressions (winds less than 34 knots) and tropical storms (winds 34-63 knots) occasionally move westward from the Philippines and cross the Malay Peninsula. Known locally as *barats*, strong winds and heavy precipitation associated with these tropical disturbances affect the northeast coast of Malaya, mostly from October through December. One of the more severe tropical storms, Harriet, passed through southern Thailand in October 1962. Harriet's maximum winds reached 55 knots.

Tropical Waves. Tropical waves are trough lines of low pressure embedded in the easterly or northeasterly flow. Tropical waves are most common during the northeast monsoon. Convergence toward the rear of the wave is often associated with shower and thunderstorm activity and severe turbulence, while unusually clear skies, a result of divergent flow, are sometimes found ahead of the wave. A wave may develop into a closed circulation and become a tropical depression.

Sumatras. Sumatras are squall lines that form in the Strait of Malacca due to the convergence of the land breezes from Malaya and Sumatra. The movement of relatively cool air over the warmer water enhances convection, thus leading to the formation of lines of showers and thunderstorms that are then driven ashore over western Malaya by the winds of the southwest monsoon. Wind speeds associated with sumatras may reach 40-50 knots; temperatures may fall 3°C in 5 minutes, but drops of 7°C have been reported. Sumatras normally move onshore between 2100L and 0400L. Their intensity increases rapidly after passing inland, and they typically dissipate within 1-4 hours. About six sumatras a month occur in July and August, and three to four a month occur in May, June, and September.

General Weather. The flow of air from the Asiatic and Pacific highs toward the equatorial low-pressure belt gives rise to the steady northeasterly winds of the northeast monsoon. The warm ocean waters surrounding southeast Asia modify the cold continental air, so the air mass is warm, moist, and unstable when it reaches the Malay Peninsula. The northeast monsoon generally begins in November and lasts until mid-March, when the flow begins to switch to southwesterly as the NETWC migrates northward over the peninsula.

The Malay Peninsula experiences extensive cloudiness throughout the year. Because warm, moist, tropical air almost continually dominates the area, variations in mean cloudiness from season to season and from region to region are small and often irregular. The mean annual cloud cover at most stations varies from 70 to 85 percent. The most common cloud type is cumulus, which frequently develops into afternoon cumulonimbus with frequent shower and thunderstorm activity. Cirrus, cirrostratus, altostratus, and altocumulus also occur almost every day.

Rainfall is abundant throughout the Malay Peninsula (rain falls on an average of 180 days a year in Singapore, for example), with most precipitation falling as short-lived but heavy showers. As in most tropical locations, the rainfall is often torrential, with flash flooding likely. Rates of fall approaching 13 mm in 5 minutes may last up to half an hour, and 24-hour amounts of 254 mm or more have been recorded at several locations. Since excessive rainfall may occur in any part of the Malay Peninsula at any time of year, there is no actual wet or dry season. Most locations, however, receive much of their precipitation during the brief transition periods between monsoons as the NETWC passes over the region. Rainfall generally decreases during the middle of the northeast monsoon (December through February) as cross-equatorial flow from the Australian heat low causes increased subsidence in the region.

Sky Cover. Cloudy skies are the rule during the northeast monsoon, especially along the east coast and over northward and eastward facing slopes. In November many stations experience 28 to 30 days with ceilings. Conditions from December through February resemble November's, with very slight improvement as the northeast monsoon draws to a close. Skies are generally less cloudy along the northwest coast due to shadowing effects from the mountains. Clear skies to prevail 5 to 7 days a month, and ceilings occur 17 to 19 days a month.

Although cloudiness and precipitation are abundant, low ceilings are relatively rare along coastal areas. Low ceilings are more frequent along the east coast than the west coast, especially during midafternoon (see Figure 8-2), as the sea breeze combines with onshore monsoonal flow to develop upslope cloudiness over higher terrain. The frequency of low ceilings increases considerably over the highlands, especially on exposed (northeast facing) slopes. Valley stations frequently have early morning ceilings below 300 feet, and clouds often obscure interior mountain peaks and ridges. Diurnal cloud patterns over most of the area occur with notable regularity. Light fog and sheets of thin stratus often form after midnight over swampy valleys, sometimes covering the lower mountain slopes, but they usually dissipate by midmorning. Convective activity causes cumulus clouds to start forming soon after sunrise over the interior, particularly on windward mountain slopes and slightly later near the coast. Between late morning and early afternoon, cumulus development increases rapidly over most of the sky. During the afternoon the cumulus often develops into towering cumulonimbus extending to 30,000 feet or more. Shortly after sunset the cumulus and cumulonimbus flatten out into shapeless masses and dissipate. Cloud cover generally decreases after sunset, though convective clouds may remain throughout the night over windward slopes and ridges. Figure 8-2 shows the diurnal nature of cloud cover, with the highest frequency of ceilings below 3,000 feet occurring during the afternoon at most locations. Conditions begin to improve in March, especially along the east coast, with the weakening of the monsoonal flow.

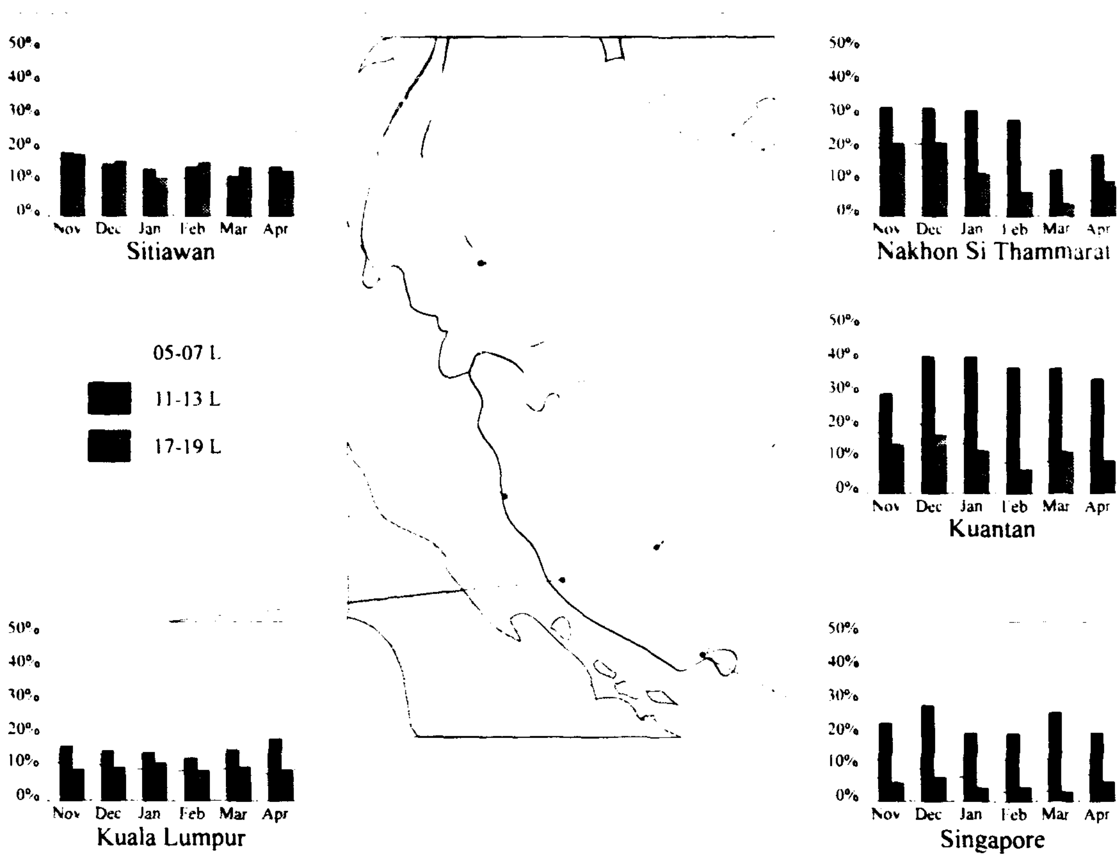


Figure 8-2. Northeast Monsoon Ceilings below 3,000 Feet. The graphs show a monthly breakdown of the percentage of ceilings below 3,000 feet based on location and diurnal influences.

Visibility. Except during heavy rainshowers, visibility is generally good during the northeast monsoon. Early morning fog and mist restrict visibility to less than 4,800 meters 20-30 percent of the time at some locations (see Figure 8-3); however, visibility rarely falls below 1,600 meters, and the mist quickly dissipates after sunrise. Morning visibility is most likely to be restricted toward the beginning and end of the northeast monsoon. Fog or low stratus can also cause poor visibility over the highlands, but unlike in the lowlands, these conditions generally do not improve as the day progresses. Heavy rainshowers are responsible for the greatest number of occurrences of visibility less than 1,600 meters. Heavy rainshowers can reduce visibility to near zero, but these conditions do not often occur over a widespread area or last very long.

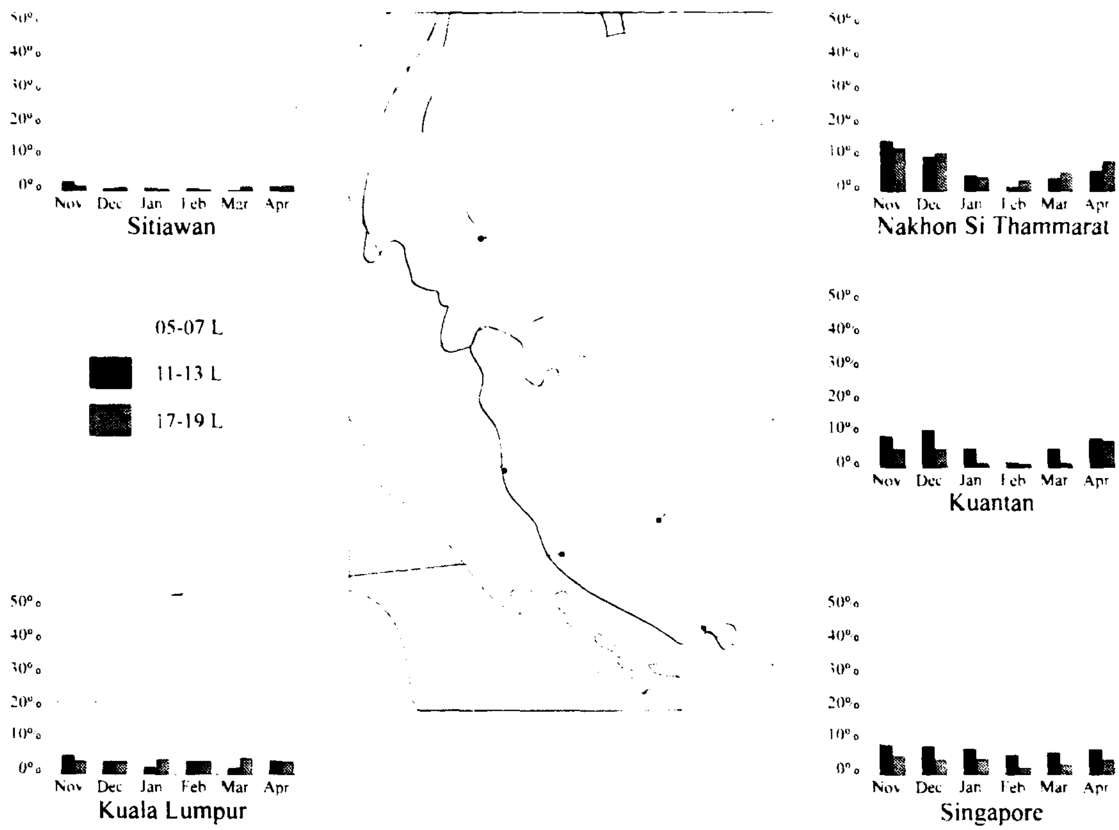


Figure 8-3. Northeast Monsoon Visibility below 3 Miles (4,800 Meters). The graphs show a monthly breakdown of the percentage of visibility below 4,800 meters based on location and diurnal influences.

Winds. Surface winds are from the northeast at most locations, conforming to the monsoonal flow; however, in some areas local conditions override the monsoon's effects. Note, for example, the winds for Sitiawan in Figures 8-4 and 8-5: Northeasterly winds are most frequent in the morning, but westerly sea breezes dominate later in the day.

The mountains' shielding effect causes light and variable winds in west central Malaya, and sea breezes along the west coast often reverse the wind direction. The northeast monsoon is strongest along the east coast, with mean speeds exceeding 10 knots in January. The highest average wind speeds are found at Mersing (128 km south of Kuantan), where afternoon wind speeds typically reach 16 to 18 knots. Along the west coast, the northeasterlies are generally lighter, averaging 6 to 12 knots, and in the interior, wind speeds are generally less than 10 knots. Although excessive wind speeds are rare, gusts over 35 knots occasionally occur, especially in December or January.

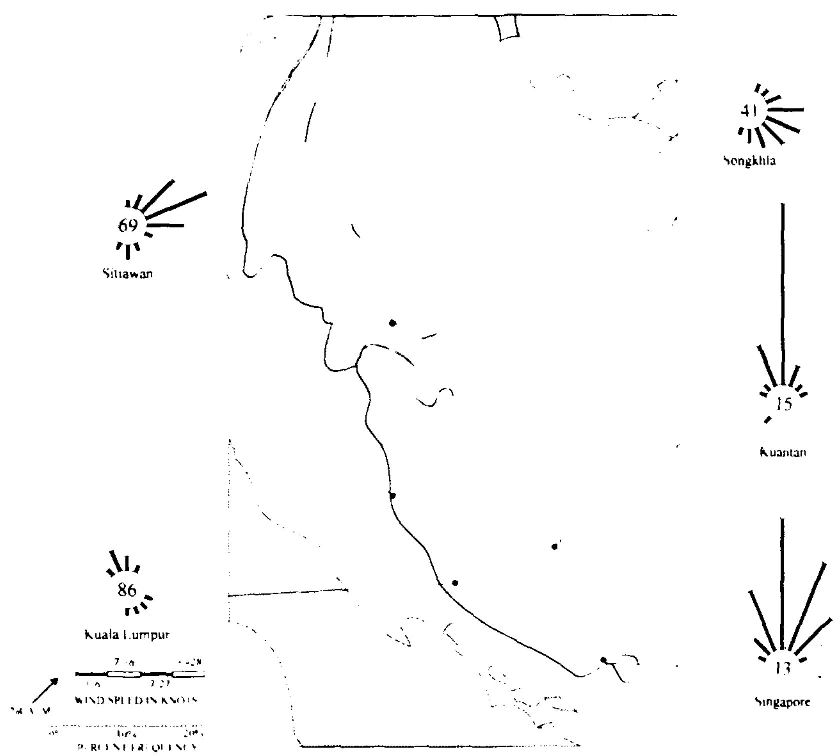


Figure 8-4. January 00Z (06L) Surface Wind Roses. The figure shows the prevailing wind direction and range of speeds based on frequency and location.

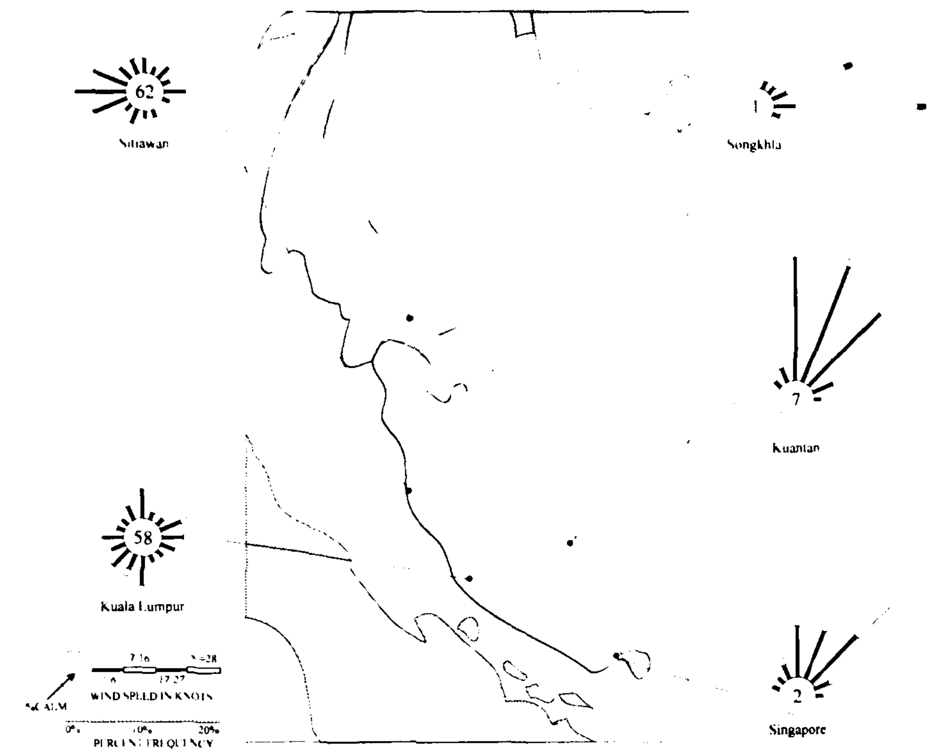


Figure 8-5. January 12Z (18L) Surface Wind Roses. The figure shows the prevailing wind direction and range of speeds based on frequency and location.

Upper-Level Winds. At upper-levels, the northeasterly flow is fairly deep in the north, where it extends to about 3,000 meters. The northeasterlies are more shallow in the south, and flow is westerly at 3,000 meters. At higher levels, westerlies are found at 9,000 meters in the north, while the south has easterly to southeasterly winds at this level. Figures 8-6 and 8-7 display representative upper-air wind roses for the peninsula.

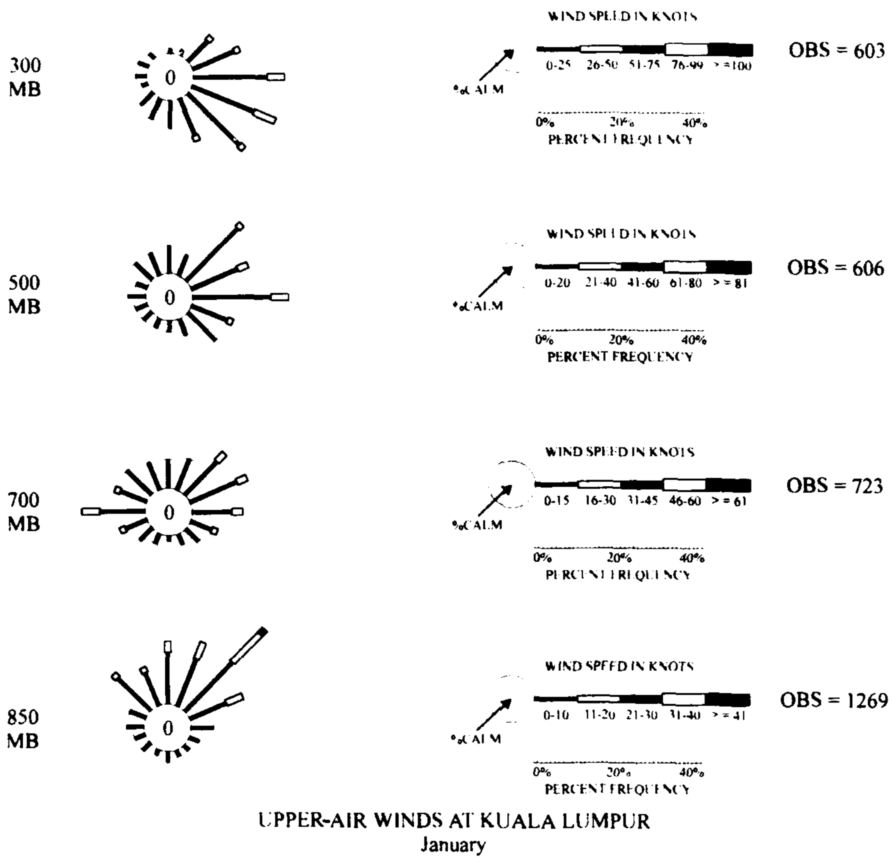
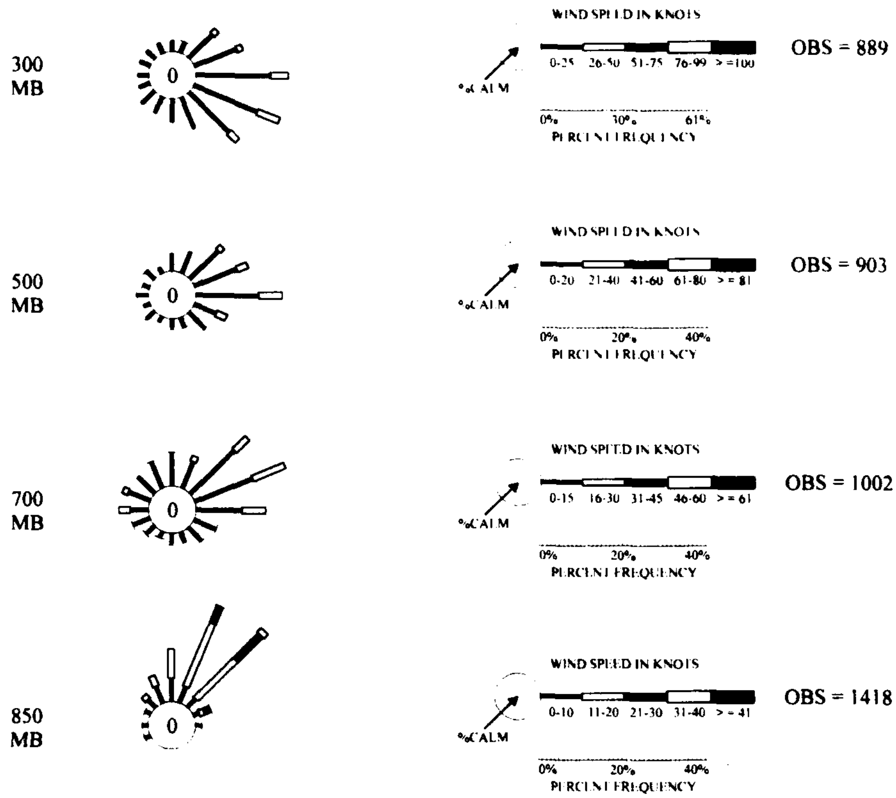


Figure 8-6. January Upper-Air Wind Roses (Kuala Lumpur, Malaysia). The figure shows the wind direction and speeds for standard pressure surfaces between 850 and 300 mb. Note: Each wind rose has a tailored legend.



UPPER-AIR WINDS AT KUANTAN
January

Figure 8-7. January Upper-Air Wind Roses (Kuantan, Malaysia). The figure shows the wind direction and speeds for standard pressure surfaces between 850 and 300 mb. Note: Each wind rose has a tailored legend.

Precipitation. As mentioned previously, the Malay Peninsula is wet year-round, unlike the majority of southeast Asia, where rainfall diminishes significantly during the northeast monsoon. As Figure 8-8 shows, southern and eastern areas receive the most rainfall due to orographically-induced showers that develop as the northeasterly winds ascend the high terrain. Monthly precipitation along the east coast is highest during the northeast monsoon, and rainfall is observed mostly from midnight to evening in November, December, and January. Most days with rainfall occur during the beginning and end of the season (see Figure 8-9). Most of the Malay Peninsula experiences 20 to 24 days with precipitation during November and 18 to 24 days during December, with some west coast stations receiving 2 to 3 days less. Eastern slopes generally average 500 mm or more during all monsoon months. During January and February warm, dry foehn winds occur along lee sides of mountains in western Malaya, reducing the region's rainfall. Rainfall in the north is reduced by the shielding effects of the southeast Asian landmass. With the March weakening of the monsoon, precipitation throughout Malaya lessens and becomes more uniform, with average amounts ranging from 130 mm in the west to 230 mm in the east.

A periodicity in the rainfall pattern in the Malay Peninsula has been noted during both monsoon seasons, with surges occurring every 4-5 days in association with westward moving tropical waves. Extended periods of very heavy rainfall along the east coast result when the arrival of a tropical wave coincides with a strong cold outbreak from China. In December 1969, Singapore received 480 mm of rain in 2 days from such an occurrence.

Despite the abundant rainfall, some regions do experience agricultural drought. Tropical rainfall is very irregular, even during rainy seasons, because a large proportion of it is due to convective rainstorms. A relatively high monthly total may fall during only a few days, but it may conceal a dry period of 2 or 3 weeks. Mean precipitation figures obscure irregular dry spells that occur in some western and central parts of the peninsula. Late in the northeast monsoon, persistent stability over the eastern coast gives rise to irregular rainfall and dry conditions, even though this area is usually very wet during the latter part of the monsoon.

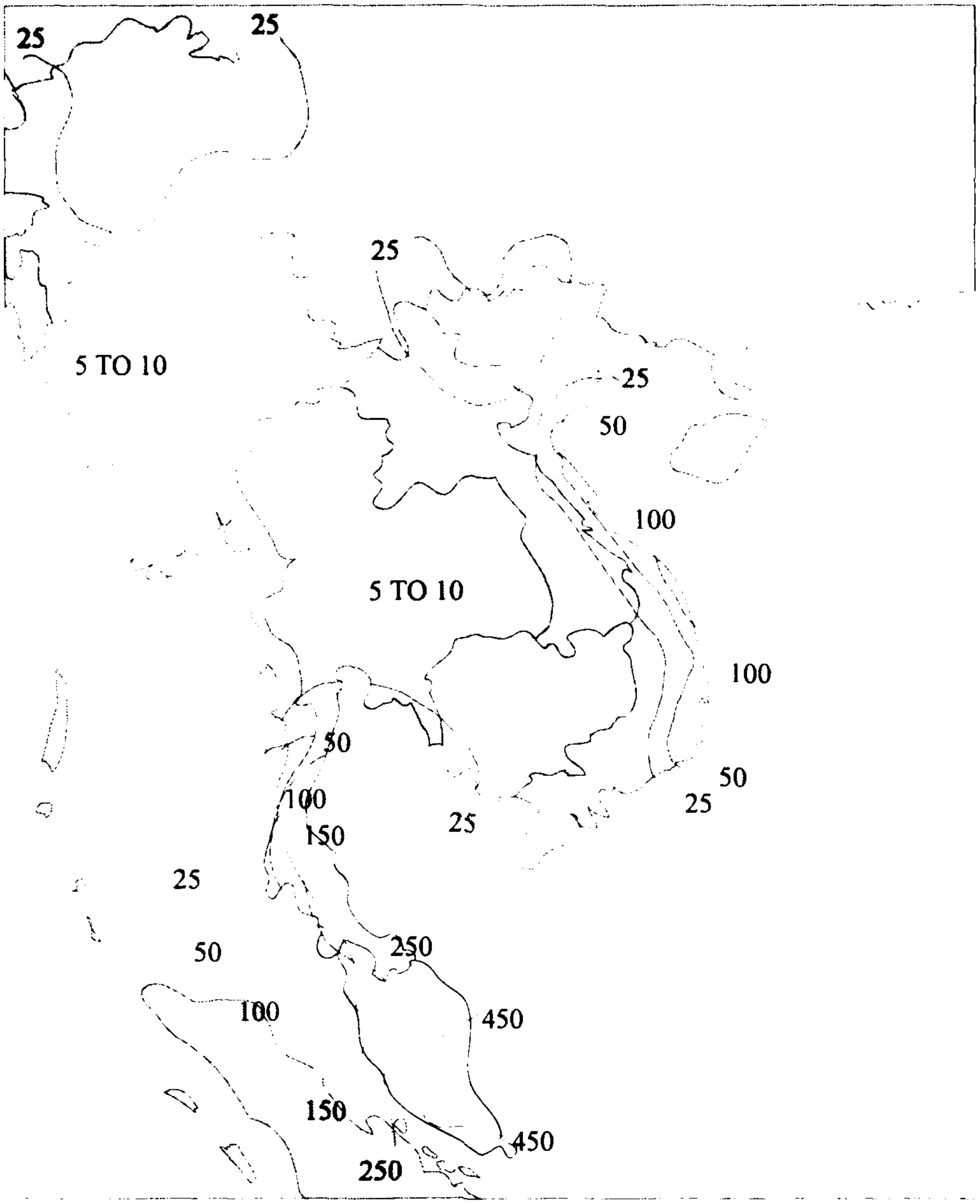


Figure 8-8. January Mean Precipitation (mm). The figure shows the largest precipitation totals are along the southern and eastern coast where orographic influences increase the precipitation.

Thunderstorms. Thunderstorms occur frequently throughout the year, though they are most common toward the beginning and end of the season as the NETWC passes over the area. Thunderstorms generally occur less frequently during the northeast monsoon than during the southwest monsoon, with January and February having the fewest thunderstorm days (see Figure 8-9).

Most thunderstorms develop in the afternoon, although they may occur at any time in coastal areas. On rare occasions thunderstorms may be associated with squall lines, but they are more commonly isolated and short-lived. Surface winds associated with these storms may be strong, at times gusting to gale force (34 knots) or more. Although these storms may include cumulonimbus, which towers to 50,000 feet, hail rarely falls at the surface and is infrequently encountered in the upper air. Higher mountain stations experience a slightly higher frequency of hail than do the lowlands.

On rare occasions, mostly from October through December, tropical depressions track far enough southward and westward from the Philippines to affect Malaya's northeast coast. The thunderstorms, heavy precipitation, and strong winds associated with these depressions are known locally as *barats*.

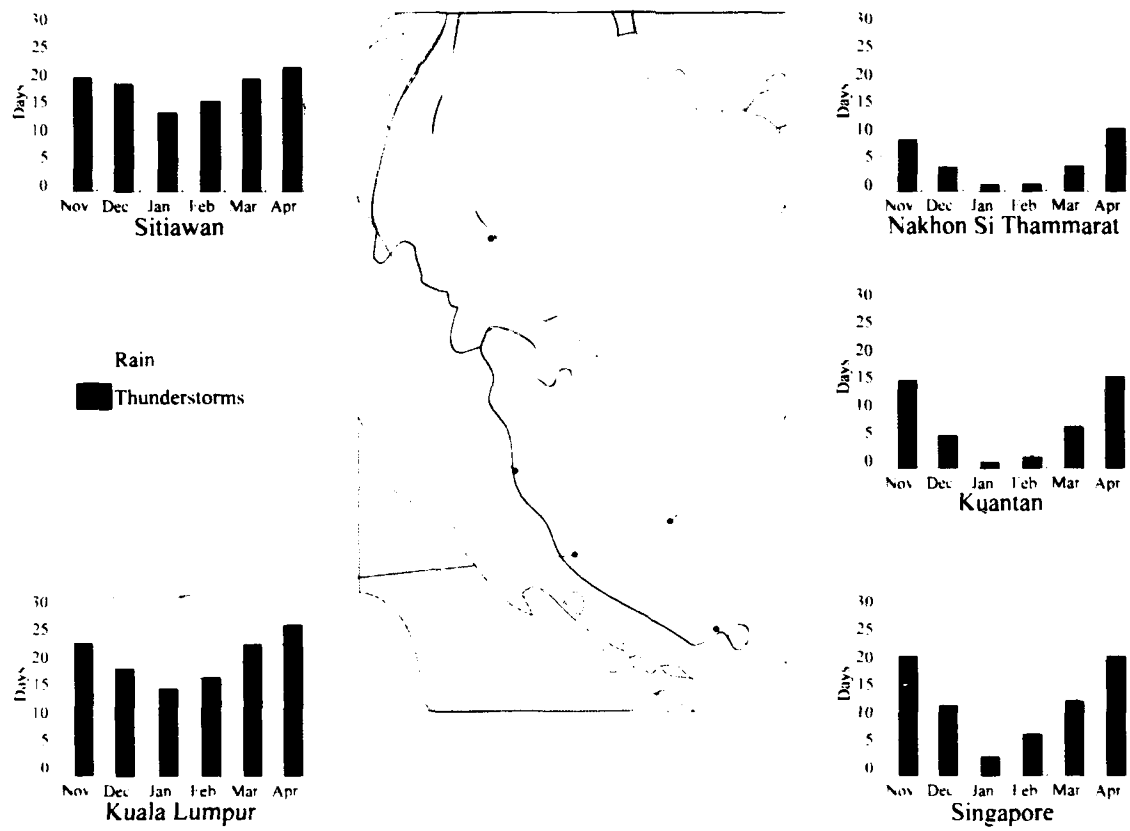


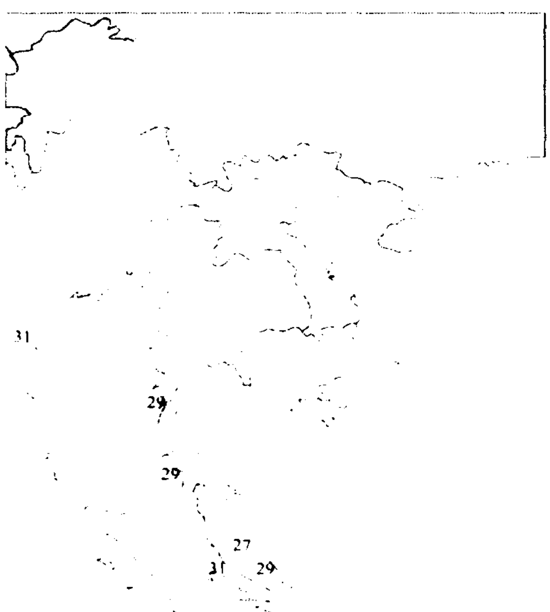
Figure 8-9. Northeast Monsoon Mean Precipitation and Thunderstorm Days. The graphs show the average occurrence of rain and thunderstorms for selected cities within the Malay Peninsula.

Temperatures. The Malay Peninsula, located entirely within tropical latitudes, has high-surface temperatures year-round at all but mountain locations. The highlands afford some relief, but even here the air is quite humid. Land and sea breezes provide some cooling, however, especially in the afternoon, and nights are often moderately cool despite persistently high humidities.

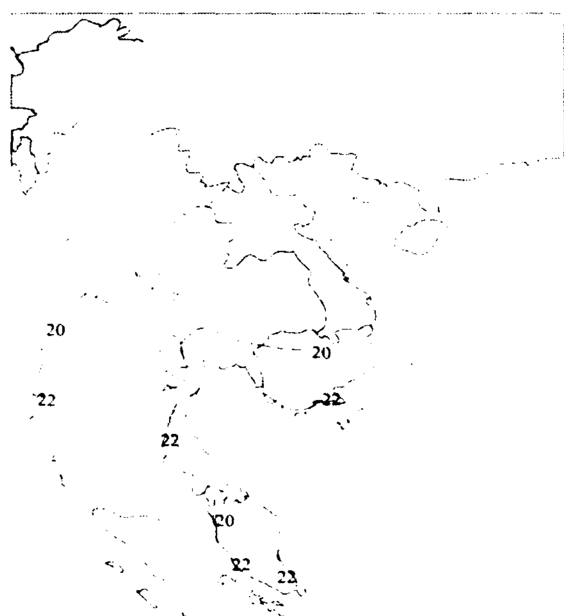
The Malay Peninsula's annual temperature regime is nearly constant, due to the stabilizing influence of the surrounding oceans. Sea-surface temperatures are about the same year-round (28°-29°C), and the peninsula's mean annual temperature is usually near 27°C. Extremes rarely go above 38°C or below 16°C. Except at high elevations, mean maximum temperatures are near 30°C; mean minimums are near 22°C (see Figures 8-10 and 8-11). The east coast is generally slightly cooler than the west coast during the northeast monsoon.

As with all tropical locations, the diurnal temperature variation is greater than the annual temperature variation. Average temperature differences from the warmest to the coolest months almost never exceed 2°C. Even local effects associated with grassy or cultivated plots, for instance, can increase the diurnal range, while locations within thickly wooded areas or near open waters have more constant temperatures. A similar temperature pattern occurs on the island of Singapore, where the annual temperature range is 1.7°C, considerably lower than the diurnal range of 8.3°C. The maximum temperature recorded over a 37-year period was 34.8°C; the minimum was 19.6°C.

Relative humidity throughout the Malay Peninsula is uncomfortably high in all months, although the northeast monsoon and transition seasons tend to be muggier at most locations. Although the difference is small, the air over western Malaya has a higher moisture content than elsewhere. As with temperature, diurnal variations in humidity greatly exceed seasonal changes. Humidity generally exceeds 90 percent in the early morning just before sunrise, but falls to 60-70 percent during the afternoon (except in showers).



Figures 8-10. January Mean Maximum Temperatures (°C). The isopleths represent the average of all high temperatures.



Figures 8-11. January Mean Minimum Temperatures (°C). The isopleths represent the average of all low temperatures.

Hazards. Typhoons come through this region any time of the year. The official season is June to November, but typhoons have been reported in all months of the year. These storms bring high winds, heavy rains, and extensive flooding when they come ashore. The most vulnerable areas are the coastal communities. Flimsy structures collapse around occupants; tides run very high and drown the low-lying areas closest to the coast. Both communities suffer extensive damage from wind, rainfall, and waves. Thunderstorms occur year-round and produce brief but intense rainshowers, lightning, and strong downbursts. Tropical disturbances, known as barats, track southwestward across the Malay Peninsula on rare occasions. They bring clusters of thunderstorms, heavy precipitation, and strong winds. Barats are known for causing extensive flash flooding and landslides in the mountains.

Trafficability. The Malay Peninsula's plentiful rainfall occurs mostly during heavy showers, and ground surfaces are often rendered impassable. Flash floods associated with these downpours are also likely.

General Weather. The NETWC's northward movement across the area in late April and early May, accompanied by increased precipitation and thunderstorms, marks the beginning of the southwest monsoon. Airflow from the Asian low and the Australian high combines to produce predominantly southwesterly winds over the Malay Peninsula from May through September. The initially cool, dry air from Australia becomes warm and moist as it passes over the ocean waters on the way to the Malay Peninsula. The strongest monsoonal flow occurs during June, July, and August; in September, as the Asian landmass begins to cool, pressure gradually rises, and the southwesterly flow weakens.

The Malay Peninsula continues to receive abundant cloudiness and rainfall during the southwest monsoon, though the rainfall pattern is quite different from that observed during the northeast monsoon. Northwest coasts and west facing slopes generally receive more rain than the southeast areas. Thunderstorms occur more frequently during the southwest monsoon, especially along the southwest coast where nocturnal squall lines (sumatras) move ashore from the Strait of Malacca.

Sky Cover. While cloud cover is not as thick as during the northeast monsoon, skies are still generally cloudy during the southwest monsoon. Cloud cover is relatively uniform along both coasts, unlike during the northeast monsoon, when the east coast is generally cloudier than the west coast. Cumulus clouds dominate low levels during the afternoon, but altostratus and cirrus also occur. Cumulus bases are generally between 1,000 and 3,000 feet. Interior valleys have low-level stratus with bases at 300 feet or less during early morning on at least half the days. Exposed stations in interior highlands may also experience these conditions on 5 to 10 days a month, but not at any particular time of day. Most locations experience 1 to 3 clear days a month during the southwest monsoon.

The diurnal cycle of cloud development and dissipation described in the northeast monsoon section is still evident during the southwest monsoon, with afternoon ceilings below 3,000 feet occurring more often at most locations (see Figure 8-12). Early morning low stratus ceilings are occasionally observed along the lowlands of the northwest coast, especially near the mouths of rivers. Convective air currents cause cumulus formation to begin soon after sunrise over the interior, particularly on windward mountain slopes, and slightly later near the coast. Around noon, these cumulus clouds increase rapidly. During the afternoon, the cumulus often develops into towering cumulonimbus extending to 30,000 feet or more. Shortly after sunset, the cumulus and cumulonimbus begin to dissipate. Convective clouds may remain throughout the night over windward slopes and ridges, and onshore winds may bring low clouds inland. Thin stratus and light fog often form after midnight over swampy valleys, but usually dissipate by midmorning.

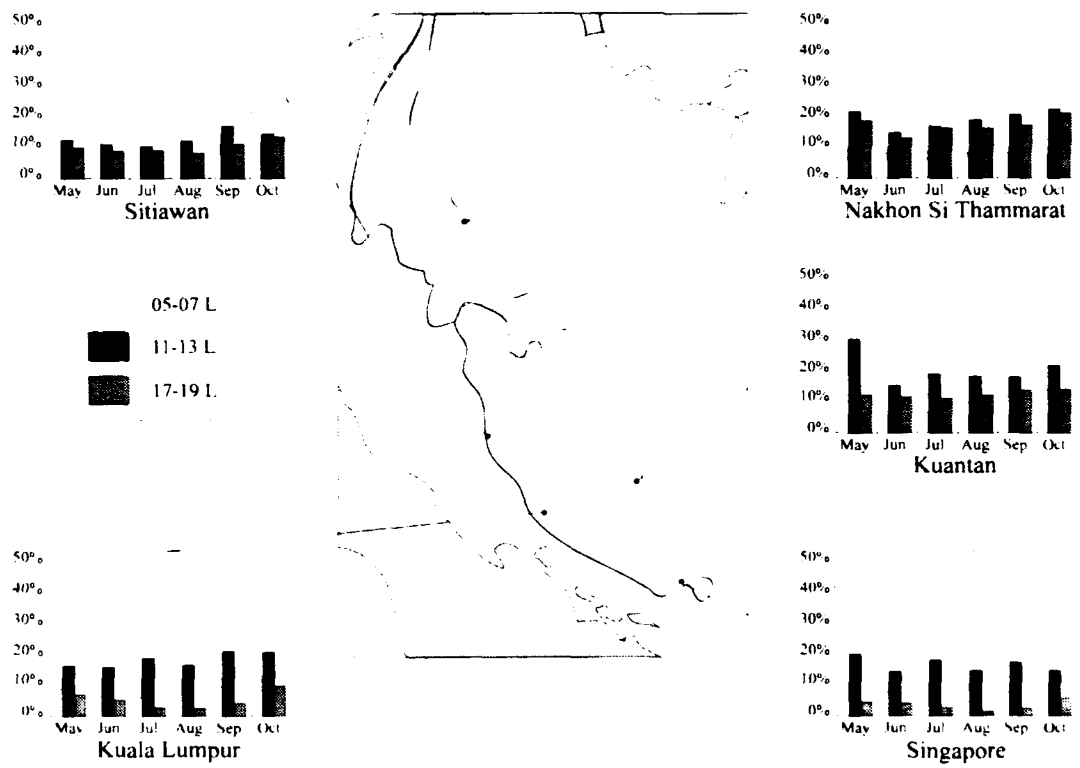


Figure 8-12. Southwest Monsoon Ceilings below 3,000 Feet. The graphs show a monthly breakdown of the percentage of ceilings below 3,000 feet based on location and diurnal influences.

Visibility. Visibility during the southwest monsoon is generally better than during the northeast monsoon, especially in the northern portions of peninsular Malaysia. Rain represents the most significant obstruction to visibility; heavy rainshowers can reduce visibility to near zero, but these conditions do not often occur over a widespread area or persist very long. Haze reduces early morning visibility at Singapore to below 4,800 meters as much as 30 percent of the time. The haze, which consists of dust from Australia, salt particles from the sea, and smoke from brush fires, usually dissipates with the first rains of the northeast monsoon. Even during haze episodes, visibility rarely falls below 1,600 meters, and conditions improve quickly after sunrise.

Early morning stratus and fog can cause poor visibility in interior valleys, but conditions improve quickly after sunrise. Cloud cover frequently restricts visibility over the highlands. Conditions improve during the day as the bases of the clouds lift, but visibility again deteriorates after sunset (see Figure 8-13).

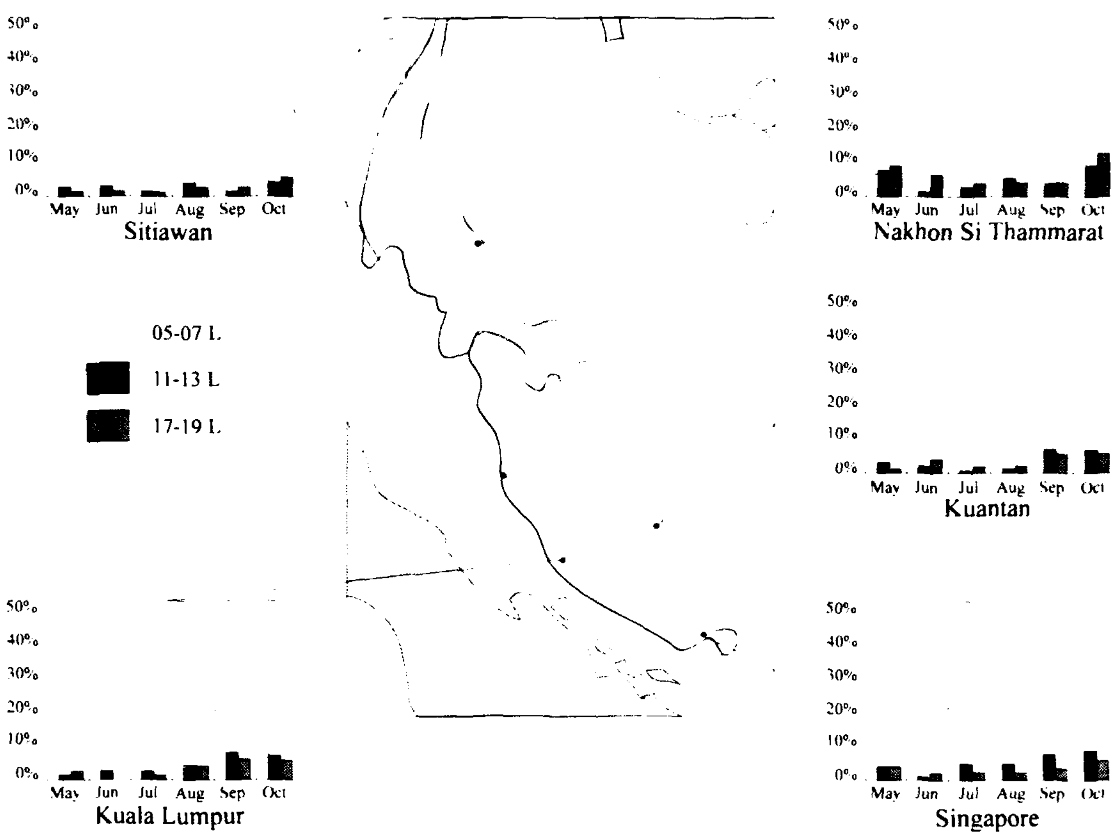


Figure 8-13. Southwest Monsoon Visibility below 3 Miles (4,800 Meters). The graphs show a monthly breakdown of the percentage of visibility below 4,800 meters based on location and diurnal influences.

Surface Winds. Southwesterly surface winds prevail over most of the peninsula (see Figures 8-14 and 8-15). The exceptions are protected inland areas and some east coast locations, where local topography and land/sea breezes overpower the general monsoonal flow. For example, a northerly component is apparent in the late afternoon wind at Kuantan, while Singapore has primarily southerly winds. Wind speeds generally average less than 10 knots, with strong winds uncommon. Gusts greater than 35 knots occur about 1 day a month; they are slightly more common on the west coast in association with sumatras. Variable winds are the rule during October as the monsoonal influence decreases.

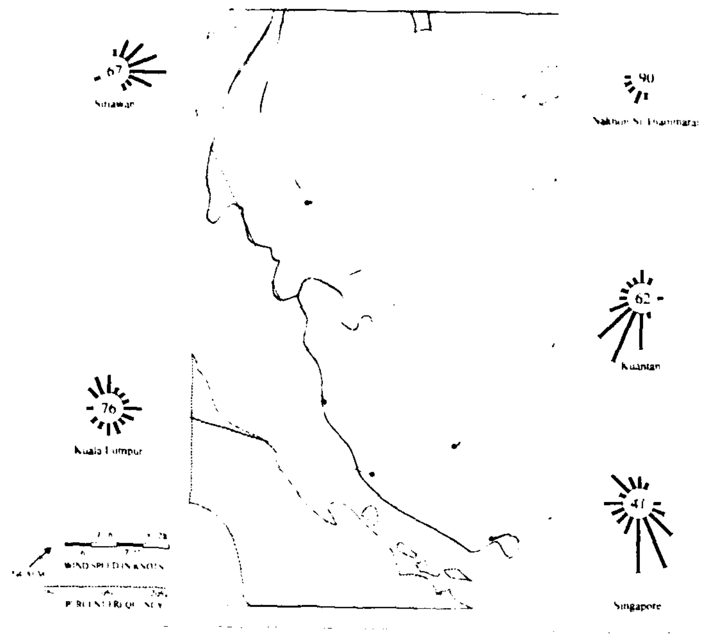


Figure 8-14. July 00Z (06L) Surface Wind Roses. The figure shows the prevailing wind direction and range of speeds based on frequency and location.

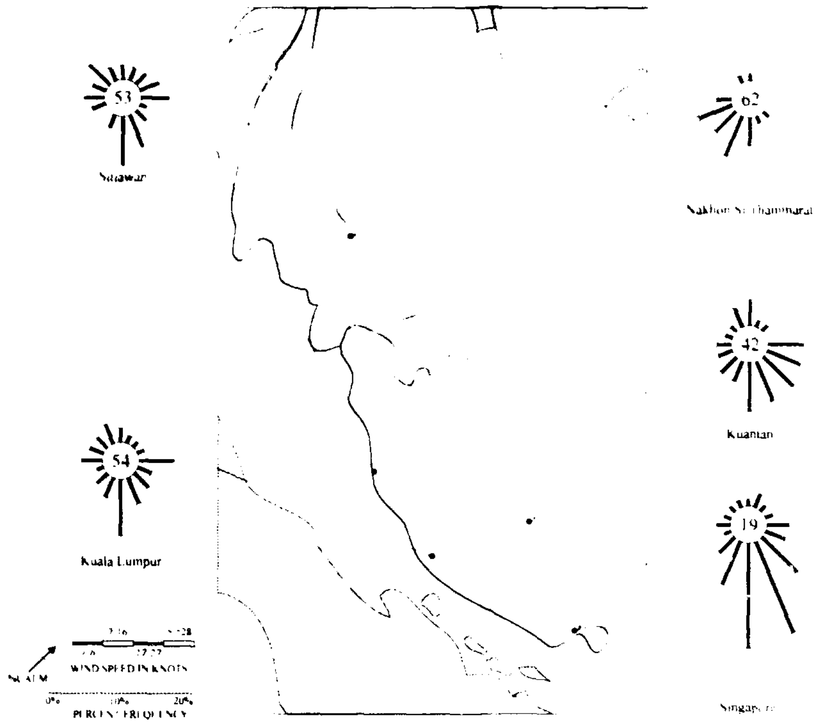
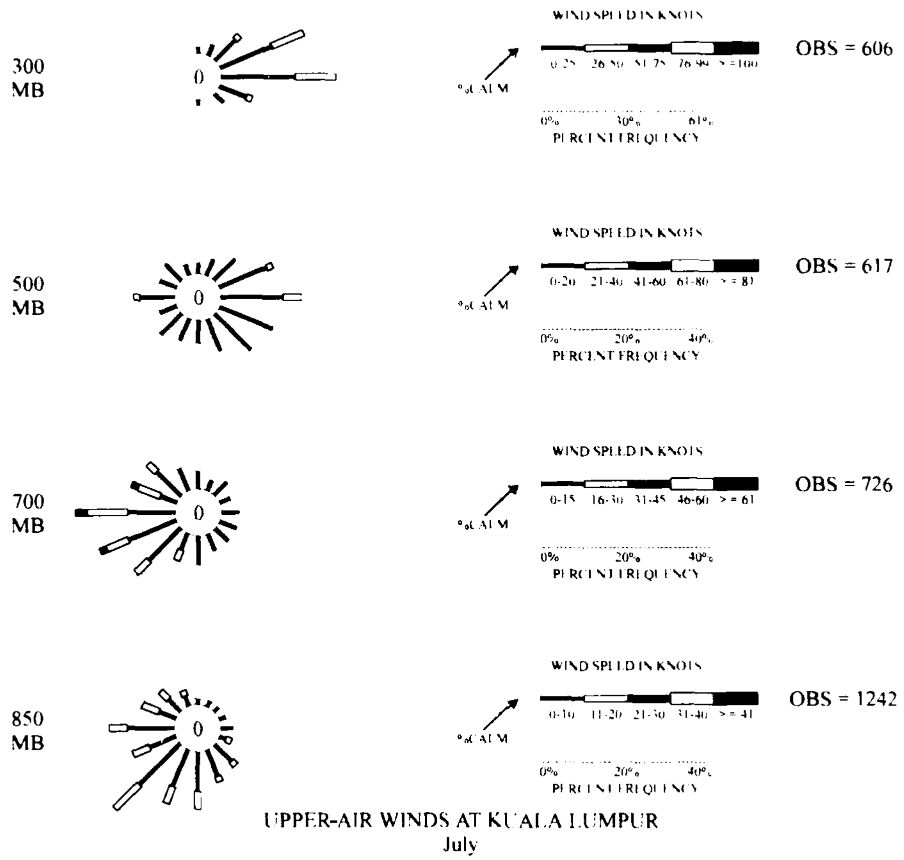
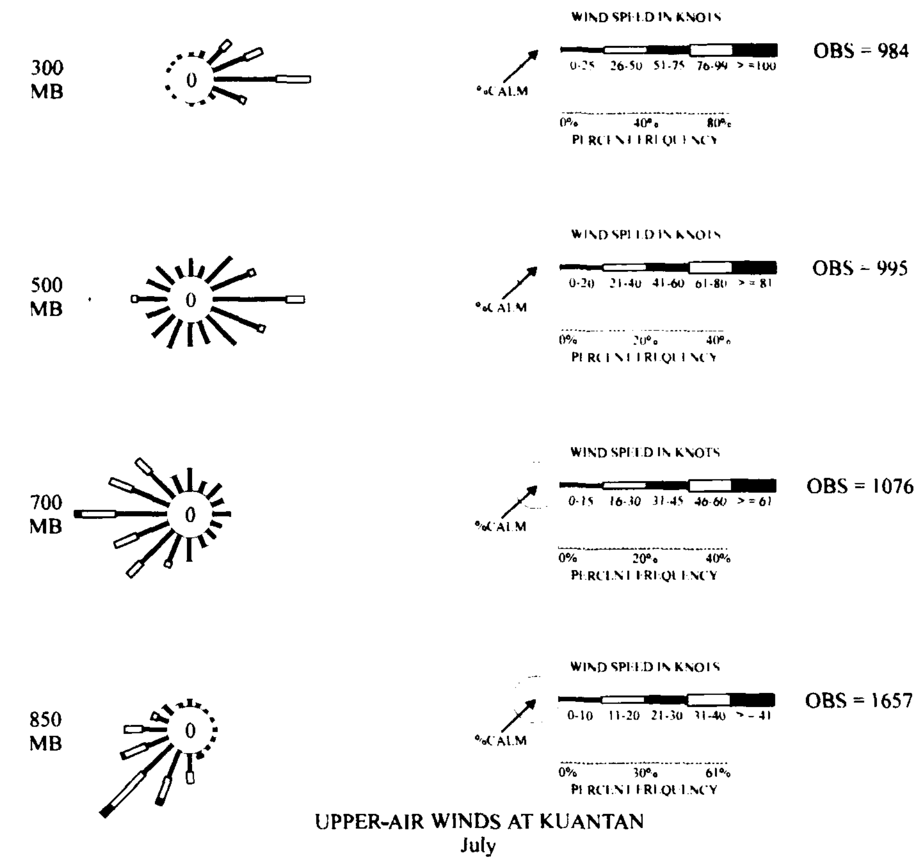


Figure 8-15. July 12Z (18L) Surface Wind Roses. The figure shows the prevailing wind direction and range of speeds based on frequency and location.

Upper-Level Winds. Upper-level winds (see Figures 8-16 and 8-17) are from the southwest below 1,500 meters, becoming westerly between 1,500 and 3,000 meters. Above 3,000 meters, easterlies dominate up to 15 km. Wind speeds are generally below 20 knots, but they average 40 to 50 knots between 10 to 15 km.



Figures 8-16. July Upper-Air Wind Roses (Kuala Lumpur, Malaysia). The figure shows the wind direction and speeds for standard pressure surfaces between 850 and 300 mb. Note: Each wind rose has a tailored legend.



Figures 8-17. July Upper-Air Wind Roses (Kuantan, Malaysia). The figure shows the wind direction and speeds for standard pressure surfaces between 850 and 300 mb. Note: Each wind rose has a tailored legend.

Precipitation. The Malay Peninsula continues to receive abundant rainfall during the southwest monsoon (see Figure 8-18), though the pattern is very different from that observed during the northeast monsoon (Figure 8-19). The west coast and west facing mountain slopes receive the most precipitation during this season, while along the east coast, rainfall is less than half that received during the northeast monsoon. During the southwest monsoon, precipitation falls primarily in the morning along the west coast, while inland most precipitation is observed in the evening. The southwest coast does not receive as much rain as might be expected, primarily due to the shielding effect of the island of Sumatra.

A periodicity in the rainfall pattern in the Malay Peninsula has been noted during both monsoon seasons, with surges occurring every 4-5 days in association with westward moving tropical waves. Rainfall increases in October as the NETWC approaches the region on its southward trek, with most locations receiving rain on 20 or more days a month.

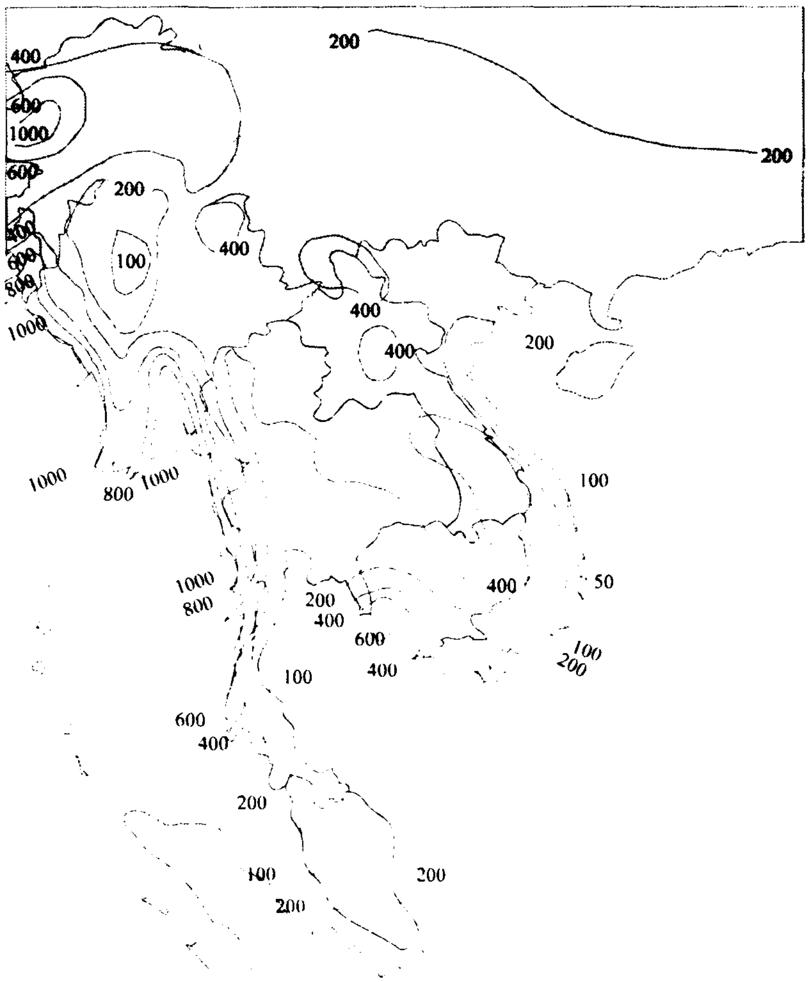


Figure 8-18. July Mean Precipitation (mm). The figure shows the impact of Sumatra on the precipitation totals associated with the southwest monsoon. The areas north of the Malay Peninsula receive much more precipitation due to their exposed western coast lines.

Thunderstorms. Thunderstorms occur frequently in all months of the southwest monsoon. The central west coast of Malaya receives more thunderstorms than other areas during July and August as sumatras, driven by the southwesterly winds, move ashore from the Strait of Malacca. Sumatras strike most frequently between Kuala Lumpur and Singapore, moving ashore between 2100 and 0400L. Wind speeds associated with sumatras may reach 40-50 knots; temperatures can fall 3°C in 5 minutes, and drops of 7°C have been reported. Storm intensity decreases rapidly after a sumatra passes inland, and the disturbance typically dissipates within 1-4 hours. About 6-8 sumatras a month occur in July and August; 3-4 a month are normal for May, June, and September.

Thunderstorms occur slightly more often as the NETWC passes over the area during the transition periods at the beginning and end of the monsoon (see Figure 8-19). The accompanying rainfall may be heavy, a result of the enormous storms generated by strong surface heating and the high moisture content of the region. Surface winds associated with these storms may be strong, at times gusting to gale force and even reach destructive force. Although these storms may include cumulonimbus towering to 50,000 feet, hail rarely falls at the surface and only occurs infrequently in the upper air. Higher mountain stations experience a slightly higher frequency of hail than do the lowlands.

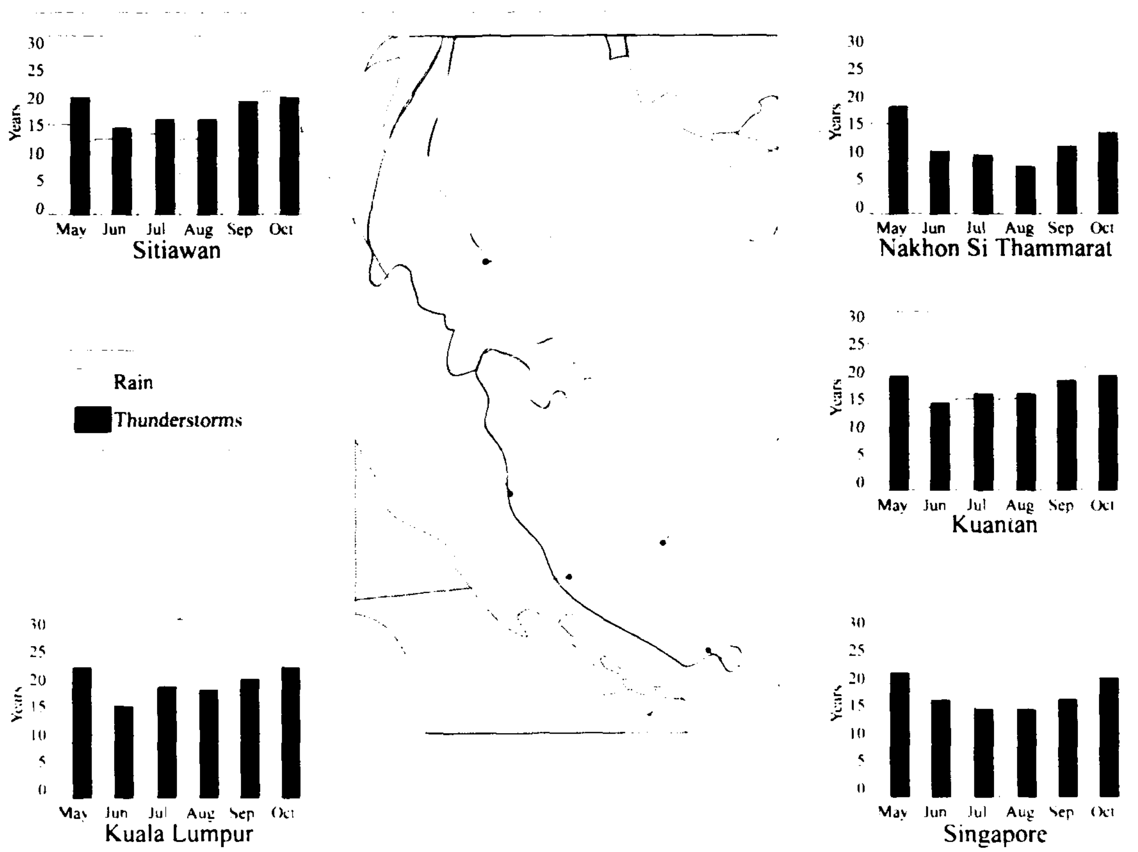


Figure 8-19. Southwest Monsoon Precipitation and Thunderstorm Days. The graphs show the average occurrence of rain and thunderstorms for selected cities within the Malay Peninsula.

Temperatures. Temperatures continue to exhibit the same uniform tendencies that were described previously in this chapter. (Refer to the description of northeast monsoon temperatures for a detailed discussion of temperature and humidity patterns). Average maximums at low elevations are near 30°C, and minimums are near 23°C (see Figures 8-20 and 8-21). Temperatures at higher elevations may be 2° to 3°C lower.

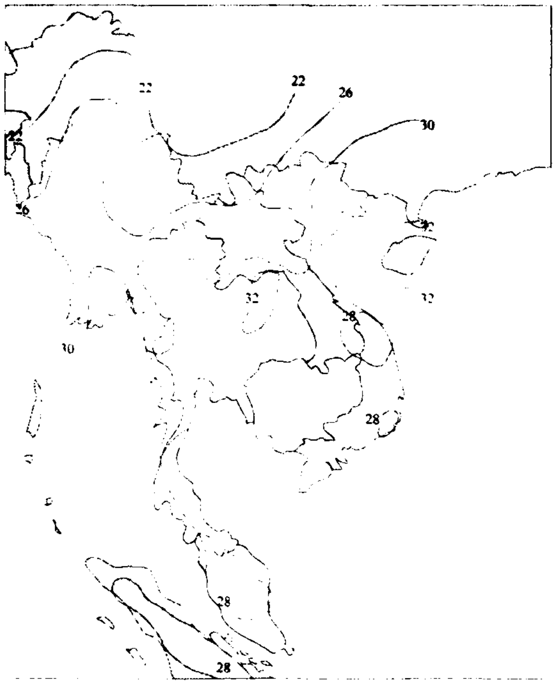


Figure 8-20. July Mean Maximum Temperatures (°C). The isopleths represent the average of all high temperatures during the middle of the southwest monsoon season.

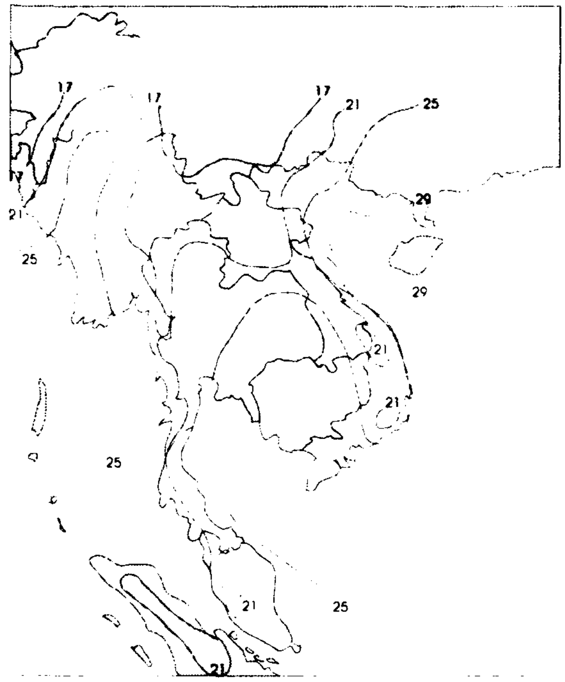


Figure 8-21. July Mean Minimum Temperatures (°C). The isopleths represent the average of all low temperatures during the middle of the southwest monsoon season.

Hazards. Regardless of the time of year, hazards on the Malay Peninsula are fairly consistent. Typhoons, tropical storms, tropical cyclones, and tropical disturbances occur. Each brings tremendous amounts of rain; bigger storms, typhoons, and tropical storms have damaging winds and storm surges. Powerful typhoons have come ashore in the Malay Peninsula with winds well in excess of 100 knots. Storms of this magnitude cause extensive damage to everything in the path. Wide-spread flooding and unusually high water near the coasts can take many lives in this poorly drained, densely populated area. Many people live and work in boat communities, and these people suffer the greatest loss of life and property. The whole infrastructure on the peninsula can be damaged or destroyed. On the smaller scale, squall lines can spring up quickly and move swiftly. Associated with localized convergence lines, these squalls produce violent thunderstorms, strong gusty winds, and curtains of heavy rain along their path. These are most dangerous to watercraft, but coastal communities are often battered by these brief but intense systems.

Trafficability. Any heavy rainfall during the southwest monsoon makes flash flooding likely. Sumatras and their accompanying thunderstorms make the west coast particularly vulnerable to poor trafficability.

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Geographical Index

Subject Index

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P

S

T

W

Y